STL Wake Turbulence Data Collection and Analysis Plan for Near-Term Procedures

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1. INTRODUCTION

The Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) are conducting a joint Wake Turbulence Research Program. The activities being undertaken are described in a Research Management Plan (RMP, Ref. 1) that distinguishes between near-term, mid-term, and long-term activities. Near-term activities, primarily conducted by the FAA, involve modifications to current ATC procedures based on safety assessments supported by extensive field data collection and analysis. Mid-term activities, to be conducted jointly by the FAA and NASA, will introduce the weather component into procedures modification, and is expected to include deployment of meteorological instrumentation in addition to the airport ASOS, to support field data collection and investigation of system requirements for the eventual operational system. Long-term efforts, conducted primarily by NASA, will investigate active solutions to mitigate the adverse effect of wake turbulence on airport operations — e.g., additional weather measurements and processing that will lead to a dynamic spacing tool.

An analysis has been conducted under the RMP of the operational procedures employed at a number of airports, particularly busy commercial airports with closely spaced parallel runways (CSPRs, less than 2500 ft separation), to determine what benefits might be derived from implementing wake mitigation methods during arrivals. A further analysis determined whether those results are attainable through procedures modification alone, defined as near-term applications in the RMP, or would require integration of meteorological instrumentation, defined as mid-term applications in the RMP. Based on this analysis, Lambert-St. Louis International Airport (STL), whose runway configuration involves closely-spaced, staggered parallel runways (**Figure 1**), was selected as the site for the first near-term test program to be conducted under the RMP. More specifically, the STL program seeks to determine whether, under reduced visibility conditions,* new procedures can enable increased arrival rates to runways 12L/12R without compromising safety. This document describes the approach to be taken with respect to acquisition, processing, and analysis of data collected from an extensive sensor suite that is being deployed at STL. This document is intended for Flight Standards (AFS-400) to ensure the data collection and analysis activities supports their needs for the subsequent safety assessment of the proposed procedure.

* Weather conditions at STL below which instrument approaches are required (Ref. 2): ceiling 5,000 ft and/or visibility 5 mi.

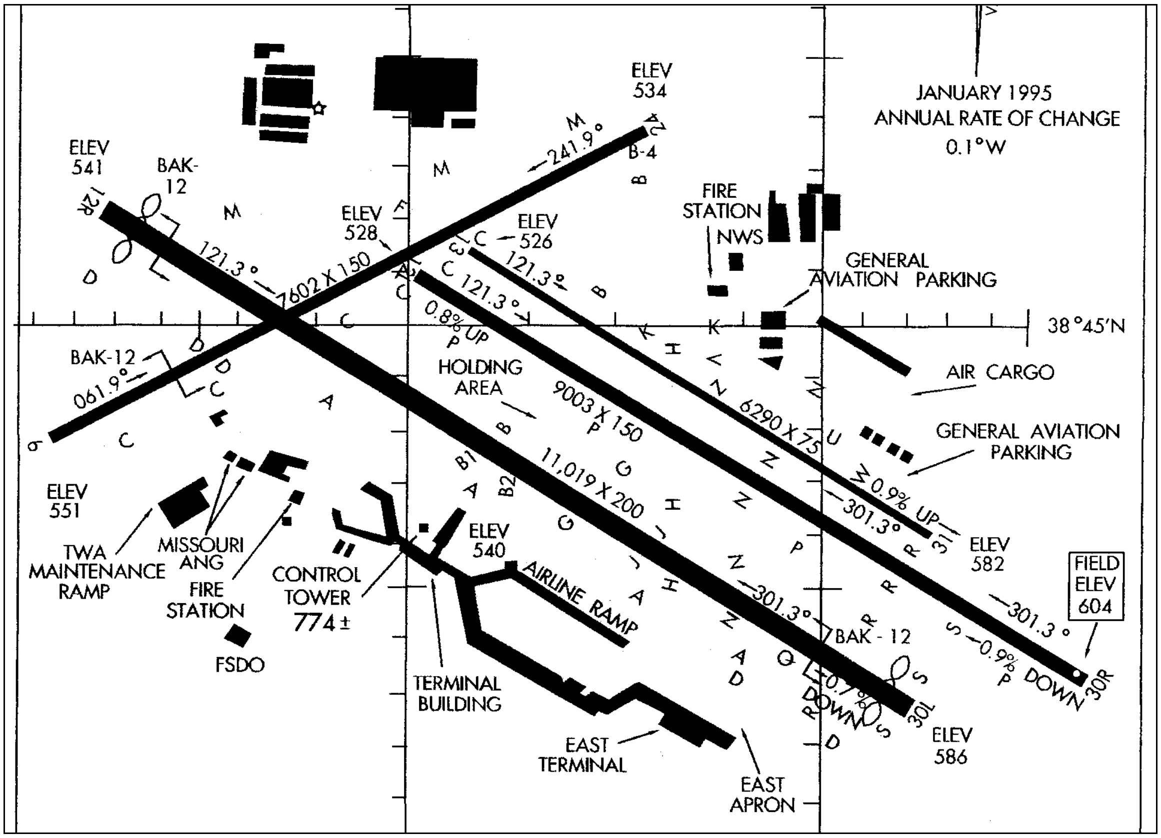

Figure 1 Lambert-St. Louis International Airport Layout

2. BACKGROUND

2.1 Nominal Wake Behavior

Wakes created by aircraft several wingspans above the ground normally descend until they reach an altitude slightly less than half a wingspan distance from the surface (termed in-ground effect, IGE). At that time, in the absence of any crosswind, the two wake vortices separate and transport laterally in opposite directions (**Figure 2**). In the presence of crosswind, for IGE wake vortices, the downwind vortex transport speed will be increased and the upwind vortex transport speed will be reduced. With sufficient crosswind magnitude, the upwind vortex may stall or reverse its direction. Wake vortices created out of ground effect (OGE) move laterally with the crosswind. Although wake decay occurs when wakes are not in contact with the ground, the decay process is accelerated during interaction with the ground in the IGE phase (see additional discussion in Section 4).

At STL, parallel runways 12L and 12R are separated by 1300 ft (centerline to centerline), with approximately a 3035-ft threshold stagger*. These runways are restricted to

* Determined from CAD drawings provided by the airport authority and validated with site surveys.

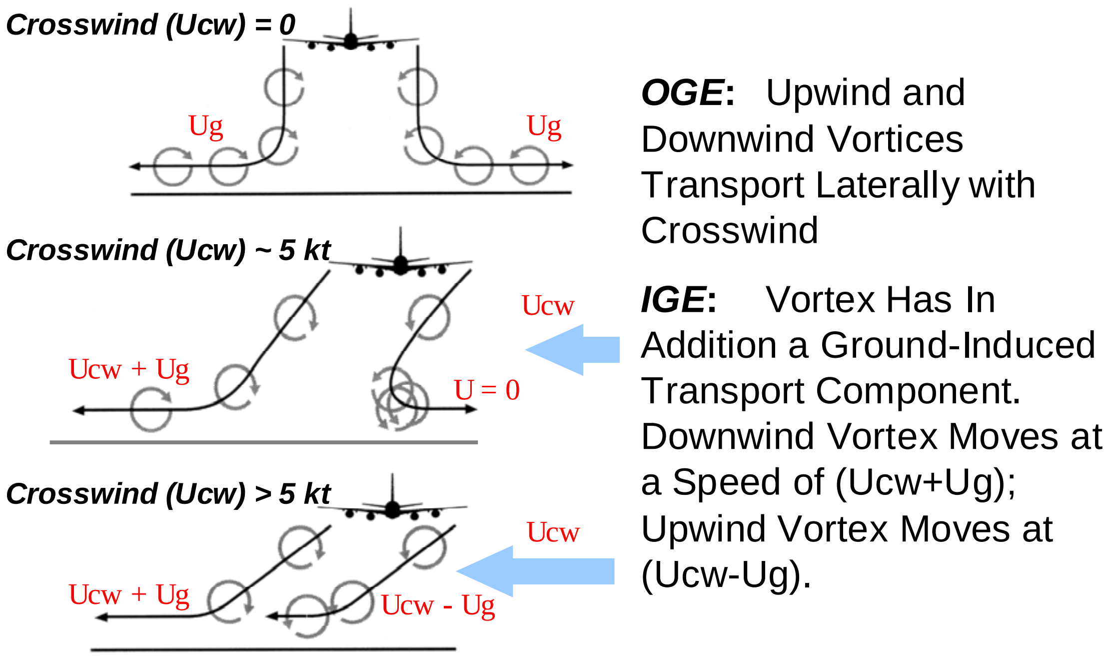

Figure 2 Horizontal Transport of Wake Vortices (Nominal Behavior)

single-runway approach operations under instrument meteorological conditions (IMC) when, typically, only RWY 12R is used, although both runways are equipped with Instrument Landing Systems (ILS). Under visual meteorological conditions (VMC), independent parallel approaches are conducted to both runways simultaneously. In less than visual conditions, independent offset approaches are used where the lead aircraft makes a straight-in ILS approach to RWY 12R and the trailing aircraft makes a Localizer Directional Aid (LDA) approach to RWY 12L.

2.2 The '2500-ft Rule'

Current Air Traffic Instrument Flight Rules (IFR) — specifically, FAA Order 7110.65 (Ref. 3), Section 5-9-6 — permit simultaneous dependent straight-in approaches to parallel runways with centerlines separated by at least 2500 ft. (Collision risk is minimized by requiring 1.5 nmi minimum diagonal separation.) However, this procedure cannot be applied to parallel runways separated by less than 2500 ft because of the possibility of a wake turbulence encounter. This restriction gave rise to the phrase '2500-ft rule.' The 2500-ft rule is intended to prevent wake encounters in situations where the largest aircraft (Heavy class) is on approach to one runway and the smallest (Small class) is behind the Heavy and on approach to the other parallel runway. Neither aircraft weight class nor cross wind direction/magnitude are factors in this current restriction.

For all intents and purposes, this rule limits operations at all airports with parallel runways separated by less than 2500 ft, regardless of the weight classes of the arrival aircraft population. However, few aircraft in the B757 or Heavy weight classes operate at STL. Therefore, if wakes from Large class aircraft can be shown never to travel the 1300-ft distance between runways, or not to reach the other runway within the context of dependent operations, then dependent IFR approaches with a minimum 1.5-nmi diagonal separation might be permissible from the wake vortex perspective. Current in-trail separations for sequential aircraft to the same runway or a closely-space parallel runway pair would not be modified by this proposed rule change.

A potentially important characteristic of the STL airport is that the 12L/12R runways are staggered (for approaching aircraft, the RWY 12L threshold is approximately 3035 ft farther than the RWY 12R threshold). This stagger may mitigate wake encounters even if wakes were to travel from one runway to the other. Current LDA operations put the lead aircraft of a paired arrival group on the lower glide slope to RWY 12R and the trailing aircraft on the higher glide slope to RWY 12L. Wake encounters are likely mitigated during such operations, as would be expected based on nominal wake behavior. Detailed discussions of these other wake avoidance alternatives will be addressed in later versions of this plan.

3. GOALS AND OBJECTIVES

3.1 Goals

The STL data collection and analysis activity has both local and national goals[*]. The local goal is obtain the data necessary to conduct a safety assessment of a new procedure for simultaneous dependent approaches of Small and Large aircraft to STL runways 12L/12R under reduced visibility conditions. It is expected that the authorization will be in the form of a waiver to the ‘2500-ft rule’ in FAA Order 7110.65 (Ref. 3), and could, but preferably would not, involve restrictions on operating conditions (as discussed in the immediately following paragraphs) in addition to those on aircraft weight classes. This waiver would be a first step in a broader effort to modify the 2500-ft rule.

The 2500-ft rule may be overly conservative, as it does not consider aircraft weight (while the corresponding in-trail separation standard does) or other parameters that can affect wake behavior. The first national goal of the data collection and analysis activity is to provide much, if not all, of the data necessary for the FAA to conduct a safety assessment of a proposed rule change from 2500 ft minimum centerline separation for dependent parallel arrivals during IMC to 1000 ft when only Small and Large weight-class aircraft are involved, without the need for imposing further restrictions on operational factors that can affect wake behavior.

If the data collection/analysis demonstrate that this first national goal is infeasible, then a second national goal will be invoked: to determine if the data support a more limited new rule for simultaneous dependent approaches during IMC to runways separated by 1000 ft or more — e.g., by imposing requirements on crosswind magnitude/direction, runway threshold stagger, relative weight classes of aircraft pairs, or combinations of these. Implementation of this second goal, if necessary, would lead to more complex rules than the first — e.g., minimum/maximum bounds on the crosswind, or a set of

[*] As employed herein, *objectives* are shorter termed than (and are the means to attain) *goals*.

combinations of permissible threshold staggers and runway separations, for which simultaneous approaches could be conducted.

Wake data will be collected at STL to enable the Flight Standards Service (AFS) to perform the necessary safety assessment. As an element of the AFS safety assessment, the data will be used to further enhance and validate wake models that are a part of the Airspace Simulation and Analysis for TERPS (ASAT) tool used by AFS in the performance of these safety assessments. Analysis of the wake data will also be used to assist AFS in the selection and design of scenarios for the safety assessments.

This document constitutes the initial data collection and analysis plans to support the needs of AFS. The plan is structured to analyze data as it is collected and to provide feedback to the initial data collection and assumptions. It is expected that early results from the data analysis may lead to refinements in the data collection plan, including sensor locations and collection methods. These early results will be coordinated with AFS to support their decision making process.

3.2 Primary Objectives

The data collection, processing, and analysis activities described in this plan are designed to meet the following objectives:

- Determine the maximum wake lateral transport distance and time for each weight class of aircraft, with particular interest in the Large and Small classes; and
- For wakes generated from Large and Small aircraft arriving on RWY 12R that transport to/under the approach corridor to RWY 12L, determine the vertical distance between the RWY 12L glide path and the height of the wake.

These objectives will be met through analysis of at least 12 months of wake data for the approaches to STL runways 12R and 12L. Twelve months provides a full cycle of meteorological conditions, and are expected to encompass the full range of winds and weather conditions that occur at STL. Based on current traffic levels, there will be approximately 72,000 aircraft approaches to runway 12L/12R during a 12-month period. These will be employed to characterize arrivals by aircraft type, meteorology, and wake detection and tracking. From these characterizations, statistically meaningful conclusions regarding wake behavior at STL can be drawn. A decision concerning collection of additional data (more than 12 months) will be made in the fall of 2004, and will involve several factors, including the number and mix of aircraft types for which data have been collected, the wind/weather conditions observed during the first 12 months, the expected future mix of aircraft types operating at STL, and any unusual/unexpected changes in operation rules/conditions. Additionally, funding to continue the test will have to be available.

As part of the effort to obtain a waiver to the 2500 ft rule at STL, a set of over 30 safety and operational issues has been identified in consultation with Flight Standards, the Airline Pilots Association and other organizations. These issues will be addressed by a number of methodologies, including analysis of the wake and ancillary data described by this plan. It is anticipated that a future version of this plan will discuss those issues being addressed by data analysis.

Presentation of processed/analyzed data will address the current STL arrival operations as well as candidate procedures designed to take advantage of a modified 2500-ft rule and provide IMC capacity improvements without decreasing current safety margins. Wake data will be catalogued with several operational factors to support this program goal. Those factors include: wake-generating aircraft type and weight class, wind conditions, ceiling, and visibility.

3.3 Secondary Objectives

The STL test site constitutes an opportunity to address some additional (secondary) objectives of the joint FAA/NASA wake turbulence program. Precision Runway Monitor (PRM) data and Wide Area Multilateration (WAM) data could be used in conjunction with sensors deployed for this test to conduct an initial assessment of aircraft conformance to localizer and glide slope navigation guidance. This information could be used by AFS to modify their assumptions on flight technical error as a part of an overall effort to enhance their models. Wake data collected during departure operations will be used to support a modification to the 2500 ft departure rule as well as research being conducted on the mid-term wind-dependent solutions for CSPR departures. Additional meteorological data will be collected to support some of the longer-term research questions being pursued by NASA associated with active methods (e.g., a dynamic spacing tool) for mitigating wake-imposed restrictions.

3.4 Rule Change Process

In support of a change to the 2500 ft rule, this data collection and analysis plan is a part of an overall process (**Figure 3**) for implementation of a waiver for STL and a rule change affecting other CSPR airports. This figure illustrates the type of activities anticipated for implementation of a waiver at STL and a rule change for CSPR airports.

The primary activities remaining are centered on the safety evaluation of the proposed rule change. The goal of that safety evaluation is to assure that the rule change results in operations that are at least as safe or safer than today's operations. At a high level, the safety goal of collision avoidance is intended to be supported through the application of the 1.5 nmi diagonal separation minimum. A preliminary collision risk assessment, represented in blue on the illustration, generally supports that intent. An initial operational feasibility assessment, also indicated in blue in the illustration, has identified potential operational applications that fit within the general constraints of the preliminary collision risk assessment. The wake data collected will drive a more detailed assessment of individual operational hazards, and are represented in green. These analyses may also impact collision risk hazard analyses, (including blunders, TCAS warnings, missed approach procedures, etc), and may also influence wake mitigation strategies. These, in turn, may influence refinements or constraints to procedural applications of the proposed rule change.

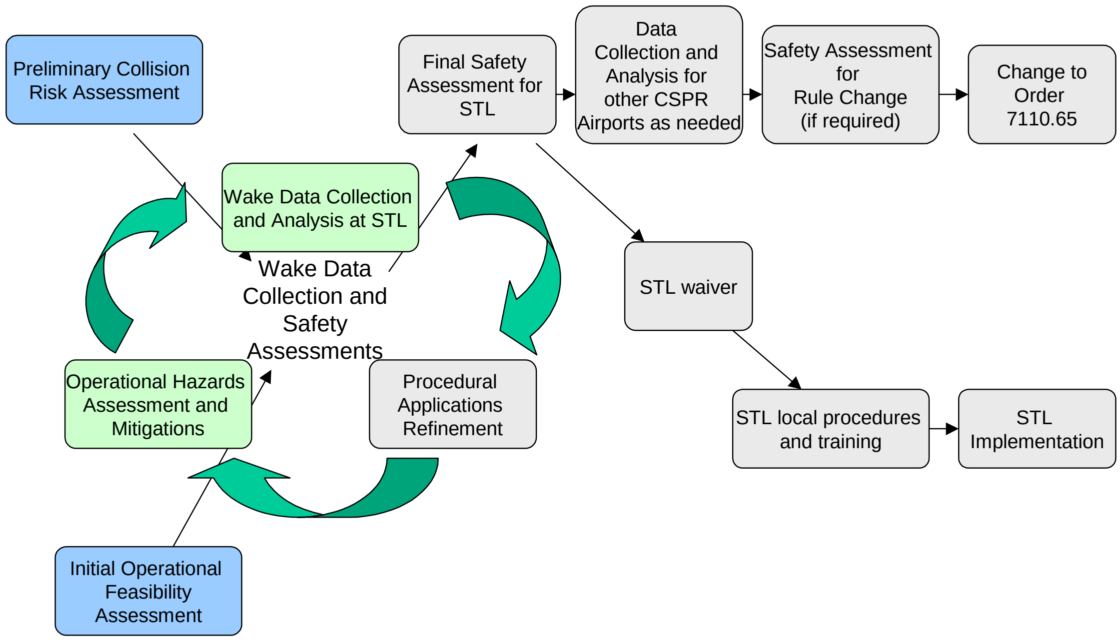

Figure 3 The Rule Change Process

Once the iterative safety assessments are completed, a final combined safety assessment is expected to be completed by AFS for STL by March 2005. When a satisfactory safety analysis is complete, a waiver for STL will be coordinated between AFS and Air Traffic. This will be followed by development of local STL procedures and training for STL controllers, leading ultimately to an implementation at STL of the proposed operational changes by Sept 2005.

The waiver for STL is a step along the way to a change to the 2500 ft rule in FAA Order 7110.65 (Ref. 3). Additional data are expected to be collected as necessary in FY06. These will focus largely on additional weather data, but may be supplemented as necessary by selected and focused wake data collection activities for selected airports, to take account of different wind/weather conditions, terrain/structures, fleet mixes, runway geometries, and other factors. A final safety assessment will be conducted. A change to Order 7110.65 will then be coordinated by the program office between AFS and Air Traffic by the end of FY06.

4. DATA COLLECTION STRATEGY

Data analysis will be performed to provide the necessary data for AFS to conduct the safety assessment of the proposed rule change to the 2500 ft minimum centerline separation for dependent parallel arrivals during IMC. The AFS certification procedure uses models of wake vortex evolution in ASAT for both in and out of ground effect. The model is used to predict wake vortex evolution in a series of vertical planes (called “tiles”) perpendicular to the aircraft course. For the In Ground Effect (IGE) wake region, the San Francisco airport (SFO) data collection and analysis project resulted in a significant amount of data at a glide path altitude of 67 ft. In order to collect data specific to STL, sensor deployments will be made that enable wake measurements at other glide path altitudes* (**Figure 4**). The tile farthest from the runway 12L/12R thresholds provides wake information on aircraft at glide path altitudes of 314 ft (RWY 12L) and 150 ft (RWY 12R); the intermediate tile provides information on aircraft at glide path altitudes of 180 ft (RWY 12L) and 31 ft (RWY 12R); and the closest tile to the threshold of RWY 12L provides information on aircraft at a glide path altitude of 120 ft.

The data requirements discussed in Section 6 and the instrumentation requirements described in Section 7 lead to the deployment configuration discussed in Section 8. The detailed analysis plan is provided in Section 12.

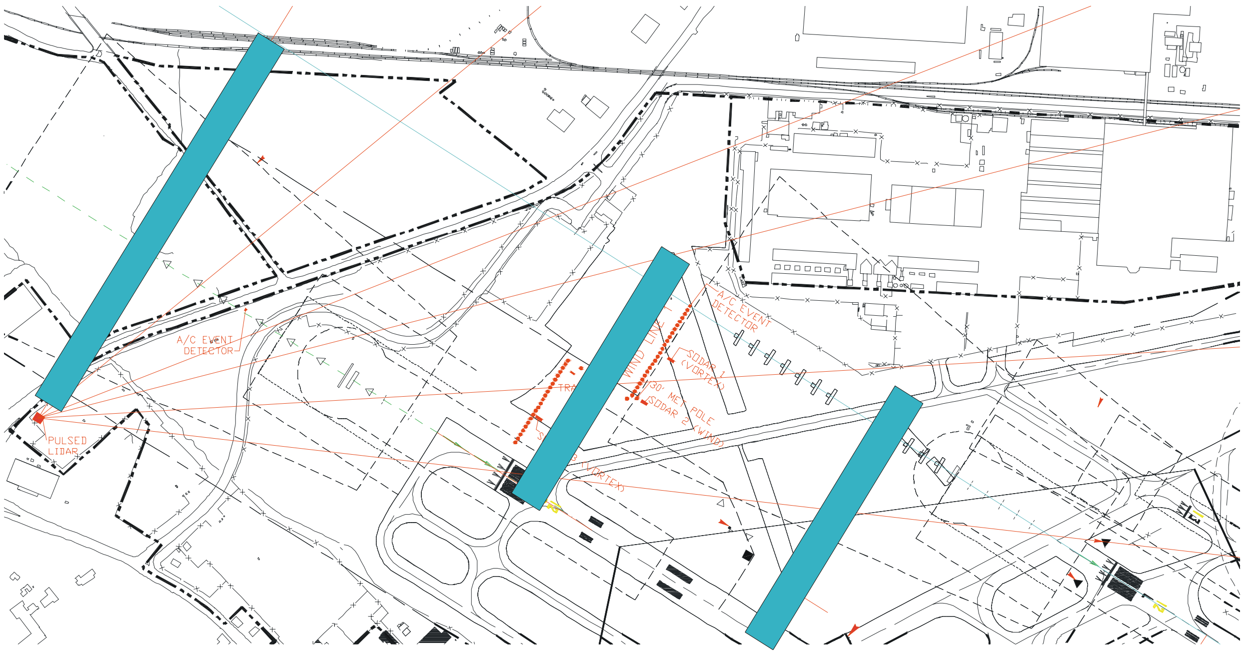

Figure 4 Data Collection and Analysis Tile Locations

Wake transport and descent above the ground are better understood and modeled than they are at ground level. The STL wake sensing assets have been strategically positioned to improve understanding of the effects of the ground on wake behavior. The fixed position lidar will track wakes out of ground effect as well as those descending into ground effect. The windlines and vortex sodars are positioned to track wake behavior affected by the ground. The windlines will track wakes as high as 100 ft above the ground, and the vortex sodars will track wakes up to 400 ft above the ground. To provide overlapping coverage in this region, the fixed location lidar will track wakes in the same tile region covered by the windlines and vortex sodars.

General characteristics of wake behavior in the OGE region are pertinent to the proposed procedure:

- Wakes transport laterally with the crosswind relative to the approach path;

* Glide path altitudes (essentially, height above runway threshold) can deviate from height above terrain when the ground under the approach course is not flat.

- Wakes descend under most of the frequently occurring meteorological conditions;
- Those meteorological conditions which retard wake descent
  - Are consistent with lower winds and shorter wake transport;
  - Also hasten wake decay;
- Wakes from larger aircraft tend to descend more quickly than those from smaller aircraft;
- Wakes from smaller aircraft tend to decay more quickly.

These characteristics will be verified with both the fixed location lidar and the mobile lidar scanning further up the approach path. The lidar sensors will track wakes in several regions well out of ground effect and will permit correlation of wake transport, descent and decay to wind conditions also sensed in those regions. In addition, a lidar sensor will be deployed to monitor wake transport IGE to provide cross verification between WL1 and the lidar.

5. STL OPERATIONAL ENVIRONMENT

5.1 Aircraft Count and Type

Table 1 is a summary of arrivals to STL runways 12L and 12R during the period April 2003 through February 2004. The monthly average is 5,785, suggesting a rate of approximately 72,000 arrivals on the 12s during a 12-month period. Arrivals were predominately (73%) on the right runway during this period, with the fraction growing beginning in November 2003.

The distribution of STL arrival aircraft by weight class is shown in **Figure** 5. Approximately 92% were categorized as Small or Large. Moreover, most of the 4% in the uncategorized (“Misc.”) group are thought to be in the Small class.

5.2 Prevailing Winds

A preliminary analysis was carried out for the purpose of forecasting the percentage of landings that can be anticipated on runways 12L/12R at STL. The analysis used one-minute resolution ASOS surface wind data from January 2003 through February 2004, collected by the National Climatic Center. ASOS wind is an airport center-field measurement at a height of 30 ft. For STL, the ASOS wind sensor is laterally located between 12L and 12R (closer to 12R), and longitudinally between WL1 and WL2 (closer to WL2). Approximately 2.2% of the data were not archived in the ASOS database.

Wind data are separated into four groups according to the wind direction relative to runway 12L/12R — i.e., headwind or tailwind, from the left or right. The first look of the data in this fashion is summarized in **Figure 6**. There is an overall bias of approximately 11% (54.4% vs. 43.4%) for the crosswind to be from 12R towards 12L (referred to as negative crosswind).

Table 1 Arrivals to Runways 12L/12R (4/03 – 2/04)

Month	Runway 12L		Runway 12R		Totals
	Number	Fraction	Number	Fraction	
April ’03	2,516	32%	5,396	68%	7,912
May ’03	1,799	28%	4,545	72%	6,344
June ’03	2,277	33%	4,565	67%	6,842
July ’03	1,881	35%	3,489	65%	5,370
August ’03	2,166	35%	3,970	65%	6,136
September ’03	2,196	30%	5,019	70%	7,215
October ’03	1,936	33%	3,922	67%	5,858
November ’03	377	9%	3,879	91%	4,256
December ’03	489	11%	4,157	89%	4,646
January ’04	409	11%	3,382	89%	3,791
February ’04	846	16%	4,418	84%	5,264
Averages	**1,536**	**27%**	**4,249**	**73%**	**5,785**

From TAMIS data provided by STL Noise Office

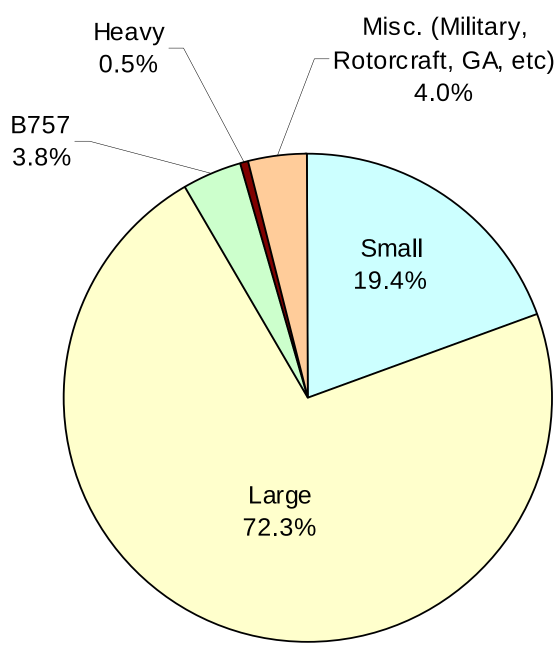

Figure 5 Weight Distribution of RWY 12L/12R Arrival Aircraft (4/03 – 2/04)

High crosswinds for the parallels occur approximately 23% of the time, necessitating use of runways 6 or 24. Of the remaining time, headwinds and tailwinds occur with approximately the same frequency. Thus favorable conditions for approaches on the 12s occur approximately 37% of the time.

As seen in **Figure 7**, (month breakdown normalized by the month, and overall data normalized by the year) January and October may have the least amount of traffic on the 12s based on the purely headwind/tailwind consideration.

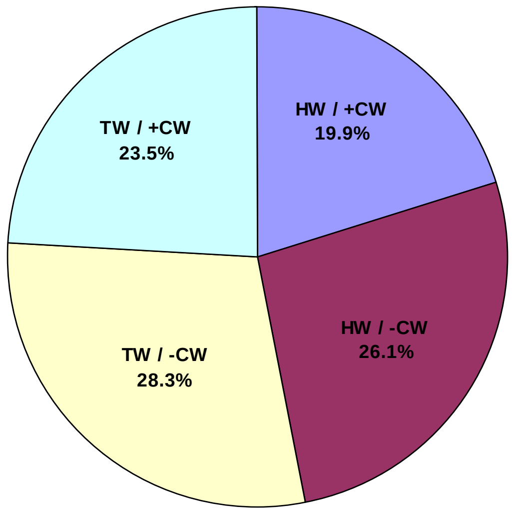

Figure 6 Wind Direction Distribution Relative to Runways 12L/12R (1/03 – 2/04)

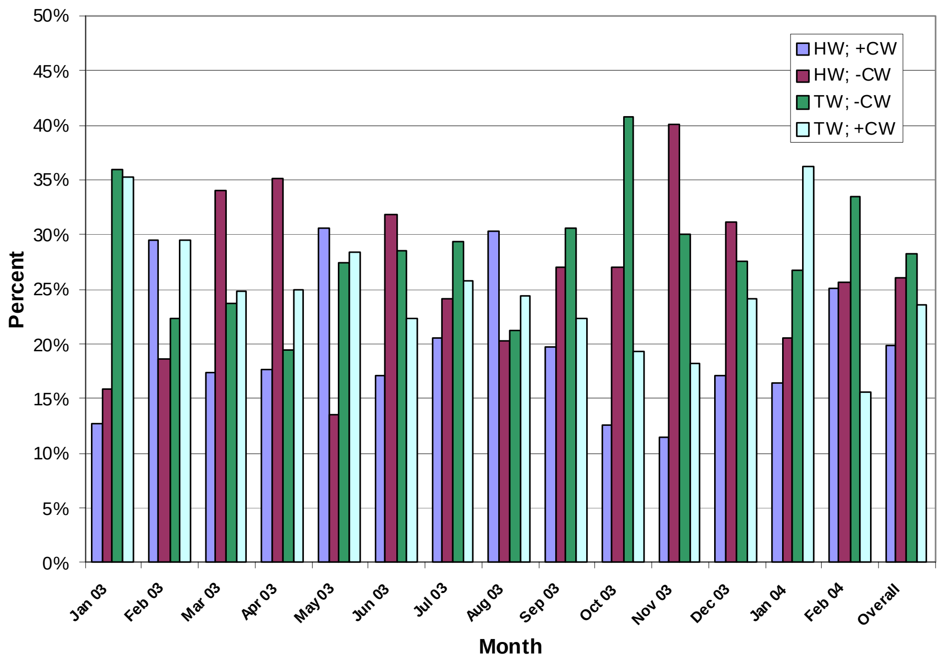

Figure 7 Wind Direction by Month, Relative to Runways 12L/12R

6. PROGRAM PHASES AND ACTIVITIES

The STL Test Program is being conducted in two phases. Phase 1 consists of the installation and verification of the sensor suite, and development of the processing and analysis procedures/techniques that will become part of the Phase 2 effort. Phase 2 consists of the accumulation, processing, and analysis of data from the sensor suite in order to produce a statistically significant set of wake behavior data. Phase 2 will begin on February 1, 2004; the schedule is shown in Section 6.4 below.

6.1 Phase 1 Activities (Site and Capability Development)

During Phase 1 the following wake sensors will be deployed:

- A fixed-position pulsed lidar measures a vortex's location and strength in a vertical scan plane, at several azimuthal angles including one transverse to the runway centerline
- Two anemometer windlines, for determining the location of a vortex transverse to a runway centerline; and
- Two vortex sodars, for determining the altitude and strength of a vortex above fixed locations.

The following ancillary sensors will also be deployed during Phase 1:

- Two laser range finders, for measuring aircraft altitude;
- Two pressure sensors, for determining aircraft passage over fixed locations;
- A wind sodar, for measuring a profile of winds aloft; and
- A 1090 MHz Mode S receiver, for determining aircraft type and operation (arrival/departure) based on messages received from the aircraft transponder.

Additional Phase 1 activities include:

- Development of appropriate database structures for data storage and access; and
- Development of methods of automatically collecting, processing, and analyzing data.

Part of these additional activities will be documentation of the data (e.g., units of measure, sensor orientations, axes directions).

In order to meet the Program objectives, it is essential that all the data be time tagged. This will be accomplished by deploying GPS time servers at appropriate instrument locations.

6.2 Phase 2 Principal Activities (Data Collection / Processing / Analysis)

The principal Phase 2 activities will be data collection, processing, and analysis. Data to be collected will include:

- Wake behavior data, including lateral transport, lifetime, height and strength, to develop the relational database for subsequent analysis;
- Ancillary sensor data, to facilitate analysis and interpretation of the wake data;
- Meteorological data from the Airport Surface Observation System (ASOS), for correlation with wake behavior data;
- Aircraft type and runway information, obtained from the airport noise office and derived from airport radar data, for cross-checking ancillary data.

Following each month of data collection, two months are allocated for processing. The processed data — files containing correlated information from the wake and ancillary sensors about each arrival — will be employed for analysis. Analysis results will be briefed quarterly, and a final report summarizing the project findings will be prepared. The findings will be used to modify the AFS ASAT model for wake behavior.

6.3 Additional Sensor Deployments During Phase 2

During Phase 2, the following additional sensors are scheduled to be deployed:

- A second pulsed lidar, for measuring wake location and strength (scheduled for June 2004);
- A third pulsed lidar, for measuring wake location and strength (scheduled for October, 2004)
- A 30-ft meteorological pole adjacent to the approach routes to runways 12L/ 12R, for measuring wind; and
- Airport Surface Detection Equipment, Model X (ASDE-X) Wide Area Multilateration system (WAM), for precisely measuring aircraft locations on approach to runways 12L/12R (scheduled for May 2004).

These additional sensors will afford an opportunity not only to enhance the data acquisition effort in support of the safety analysis of the near-term procedure, but also to extend the utility of the data sets acquired to broader applications such as mid- and long-term wake activities as defined in the RMP. For example, deploying an additional pulsed lidar in multiple locations, perhaps further up the glidepath, will allow cross-checking the data collection strategy in order to ensure that the selected wake measurement locations are optimal for determining wake behavior in connection with evaluating a dependent parallel approach procedure at STL. In addition, the second pulsed lidar can also be deployed to further verify IGE and OGE wake behavior in the context of STL operations for both arrivals and departures. Additional data collection and analysis plans will be developed in support of mid and long term research activities and will be made available at a later date.

The multilateration system at STL will allow crosschecking of aircraft flight paths with the currently deployed laser range finders and pressure transducers, in order to reduce the uncertainty of aircraft position with respect to initial wake position. These data may be correlated with wind measurements, to determine patterns.

6.4 Phase 2 Schedule and Milestones

Phase 2 will commence on February 1, 2004. The schedule is shown in **Figure 8**.

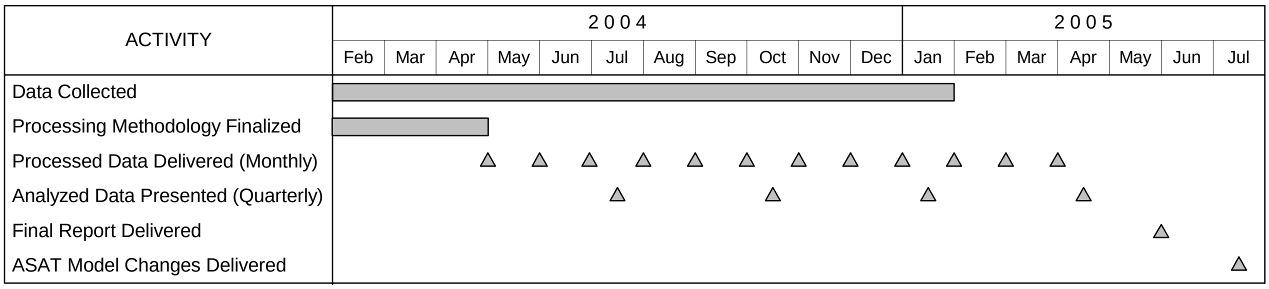

Figure 8 Phase 2 Schedule and Milestones

6.5 Resources

Activity	Labor Months
Data Collection / Quality Assurance	18
Processing Methodology Finalized	12
Data Processing	60
Quarterly Briefings	8
Final Report	6
ASAT Model Changes	6

7. DATA REQUIREMENTS

The data requirements for effective evaluation of the proposed STL arrival procedures are as follows:

- Wake transport characteristics, obtained using multiple wake sensors at various sites:
  - Location, as a function of time since aircraft passage;
  - Height, as a function of time since aircraft passage; and
  - Strength, as a function of time since aircraft passage.
- Aircraft arrival information for RWY 12R and RWY 12L:
  - Runway;
  - Event time;
  - Aircraft manufacturer/model (from which weight is derived); and
  - Altitude.
- Meteorological information from airport ASOS:
  - Airport wind speed and direction;
  - Visibility; and

- Ceiling.

- Wind information at locations near wake sensors:
  - Magnitude and direction.

8. INSTRUMENTATION REQUIREMENTS

In order to provide the data required, installation of diverse instrumentation systems will be necessary:

- Wake transport characteristics using multiple wake sensors at various sites:
  - Government owned CTI pulsed lidars;
  - Government owned ground based R.M. Young model 27106R propeller anemometers arranged as two windlines with poles nominally 25 ft apart;
  - Government owned AeroVironment Vortex Sodars (2).
- Aircraft arrival information at RWY 12R and RWY 12L:
  - Government owned Paroscientific pressure transducers (2);
  - Government owned Riegl laser ranging devices (2);
  - Government owned Rannoch Mode S squitter receiver.
- Wind information at wake sensor locations:
  - Government owned AeroVironment wind sodar;
  - Government owned ground based R.M. Young model 27106R propeller anemometers as part of two windlines with poles nominally 25 ft apart;
  - Government-owned three-axis anemometer on 30-ft meteorological pole.
- Airport systems and databases:
  - Airport Surface Observation System (ASOS) 1 min and 5 min data packages;
  - Total Aircraft Management Information System (TAMIS).

9. INSTRUMENTATION CONFIGURATION

Figure 9 is a layout of STL. It shows the locations of the wake and ancillary sensors and the altitude ("Alt.") of the glide path associated with runways 12L and 12R at points when the runway centerlines intersect the fixed-position pulsed lidar vertical scan planes. **Appendix 1** provides the sensor locations in tabular form. Sensor locations have been selected to provide the required information concerning wake and ancillary phenomena behavior, while adhering to the limitations imposed by the STL geographical configuration and ongoing construction activities at the airport.

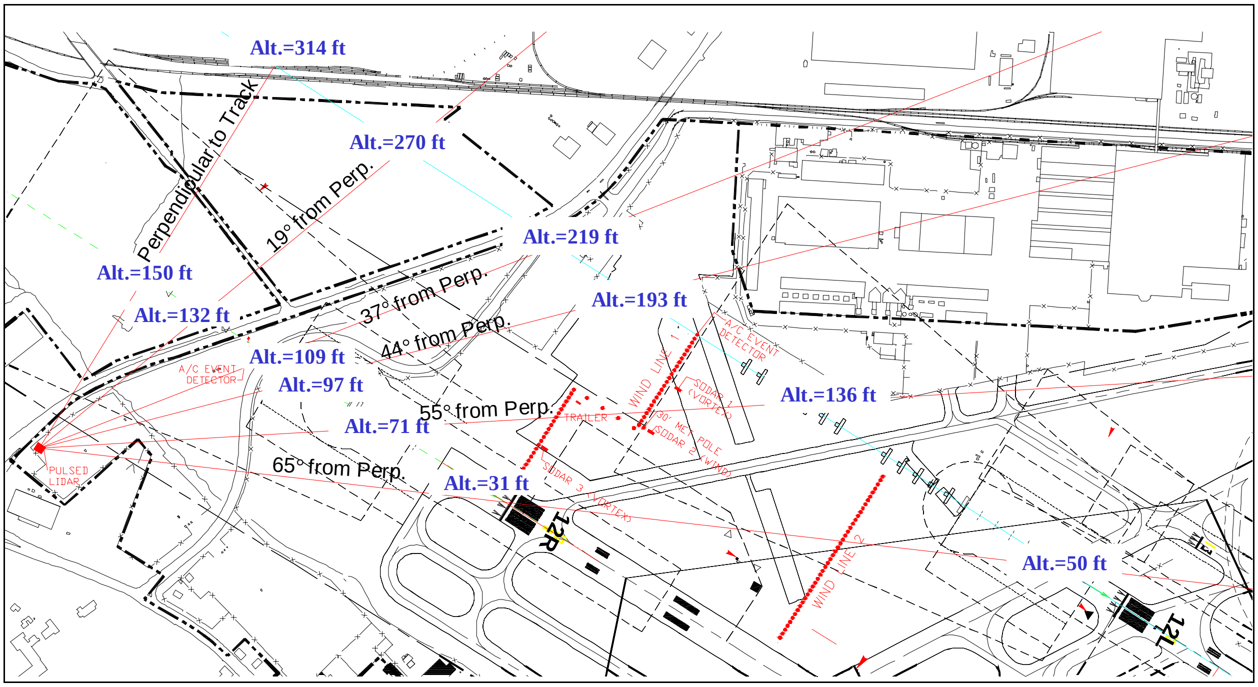

Figure 9 Sensor Layout (CAD Drawing)

9.1 Wake Sensors

The wake sensors to be deployed are as follows:

- Pulsed lidar (up to 3) – An active optical sensor with long distance (up to 5.4 nmi) wake tracking capability that provides measurements of wake lateral position, wake height, and wake strength. An additional advantageous characteristic is its ability to scan in multiple vertical planes. Coverage will include OGE (limited only by aircraft position), NGE, and IGE, including scan angles coincident with windlines and vortex sodars to enable comparisons;
- Windline arrays (2) – Wind measurement systems (arrays of propeller anemometers mounted on poles) for determining the wake-induced crosswind and, through analysis, the wake lateral position. Two such windlines are deployed at different positions along the aircraft arrival path and span the region between the arrival runways. Each windline is capable of sensing wakes up to 100 ft above the ground; and
- Vortex Sodars (2) – Active acoustic sensors that measure wake height and strength directly above the sodar locations up to a height of 400 ft.

9.1.1 Pulsed Lidar

The fixed-position pulsed lidar (**Figure 10**), PL1, positioned in a parking lot close to the American Airlines Training Center building, is located some distance from the thresholds of the two parallel runways. See Appendix 1 for the precise distances from the centerlines and the thresholds of the two parallel runways.

Figure 10 Pulsed Lidar Installation

The pulsed lidar will be used primarily to track wakes in a vertical plane — either perpendicular or at an acute angle to the ground track. **Figure 11** illustrates a vertical scan, consuming approximately 5 sec. The azimuthal scan angles of 0, 19, and 37 deg provide coverage of glide path altitudes between 314 ft and 109 ft. An additional angle of 55 deg (from perpendicular to the runway centerlines) will be used to correlate lidar measurements with windline measurements and to extend the research capabilities of the lidar.

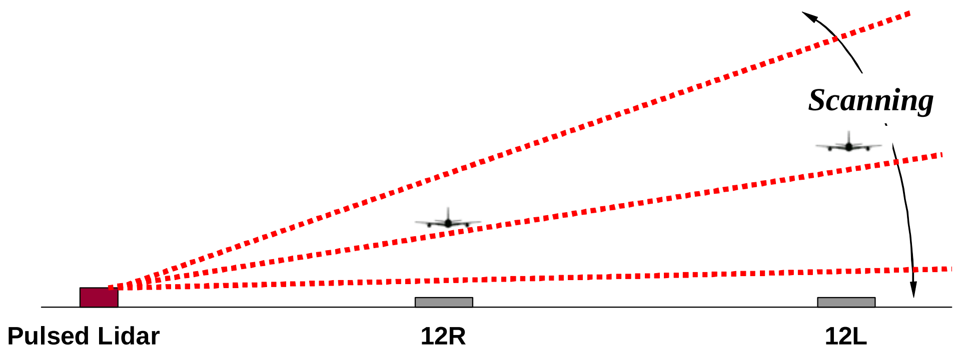

Figure 11 Pulsed Lidar Vertical- Plane Scan (5 sec period)

The lidar will sequence through the azimuthal angles selected, spending 15 min at each angle. This scheme provides lidar coverage of the most critical region for aircraft wake encounters — along the approach corridors from the middle markers to the thresholds. For approaches to RWY 12L, the lidar coverage will include wakes generated OGE transporting to IGE. Similarly, the lidar will cover vortices generated along the glide path to RWY 12R ranging from slightly OGE to IGE.

The fixed-position pulsed lidar will capture wakes in only one horizontal angle for each arrival (with the exception of those arrivals that coincide with the automated changing of scan angles or to/from wind mode). The scan angles are designed to provide early indication of the most critical region for data collection; the scan sequence and set of scan planes may be modified as a result of those findings. While extreme visibility limitations below CAT I minimums might affect the performance of the pulsed lidar, the other wake sensors will provide overlapping coverage. For the ceilings and visibilities proposed applicable to the proposed procedure change (down to CAT I minimums) all sensors are expected to perform adequately. It is also the case that during some IMC conditions, the effectiveness of the pulsed lidar is considerably reduced. However, the remaining wake sensors, windlines, and wind and vortex sodars will continue to provide wake and wind data.

The fixed-position pulsed lidar is strategically located to collect wake data over the geographic area where wake behavior is expected to determine the limits of the proposed procedure change. These expectations have been developed over several decades of experience with wake turbulence data collection and analysis campaigns. A second pulsed lidar, PL2, will be used during the data collection and analysis phase to verify fixed sensor locations and data collection methods. This sensor will be placed at a number of locations along the approach corridor to runways 12R and 12L, to collect wake data from a variety of sensing geometries and locations along the final approach course. The specific schedule and site locations will be coordinated with AFS and documented in an updated version of this plan. The data collected from the second pulsed lidar may be used to modify the locations of the fixed sensors or the data collection methods as recommended by AFS. A third pulsed lidar, PL3, will be deployed to provide cross verification measurements at the Windlines.

9.1.2 Windlines

Two Windlines will be used to obtain IGE wake transport data between the two runways. The locations of the Windlines are shown in relation to the two parallel runways in **Figure 9**. A summary of number/orientation of the anemometers is shown in **Table 2**. See **Appendix 1** for the precise distances of the windlines from the centerlines and the thresholds of the two parallel runways.

Table 2 Windline Anemometer Summary

SENSOR	Height (ft)	Verti-cal	Head Wind	Cross Wind	TOTAL
Windline 1A	12	1	1	23	25
Windline 1A	6		1	1	2
Windline 1A	3		1	7	8
Windline 1B	12			4	4
Windline 1C	12			11	11
Windline 1C	3			20	20
Windline 2A	6		2	16	18
Windline 2A	3		2	13	15
Windline 2B	6		1	12	13
Windline 2B	3		1	18	19
TOTALS		**1**	**9**	**125**	**135**

9.1.2.1 Windline 1

Windline 1 (WL1, **Figure 12**) will be seen first from an approaching aircraft. It is located in a region scanned by the pulsed lidar when the azimuth scanning angle is 55 deg from perpendicular to the aircraft tracks. WL1 is made up of three sections: Section A starts at the extended runway 12L centerline and runs 725 ft perpendicular to the centerline to approximately mid-way between the two runways; Section C starts near the runway 12R edge and runs perpendicular to the centerline of runway 12R to approximately mid-way between the two runways. Section B runs parallel to the runways, linking the inside ends of Sections A and C.

Figure 12 Windline 1 and Vortex Sodar (During Installation)

WL1 is primarily made up of 12-ft poles with an anemometer on the top (termed "12-ft anemometer poles"). However, TERPS constraints require shorter poles near the runway edges, where 3-ft anemometer poles are used. Near the transitions from 12-ft to 3-ft poles, several 12-ft poles also have anemometers at the 3-ft height to ensure continuous wake tracking over the entire windline. Anemometer poles are spaced nominally 25 ft apart. WL1 anemometer data will be sampled and digitized at 10 samples per second. However, averages of five consecutive samples will be stored in the data file, resulting in a 2 Hz rate for the stored data.

WL1 will provide data for wakes traveling from runway 12L toward runway 12R at heights up to 100 ft above the ground. WL1 will provide similar data for wakes traveling from runway 12 R toward runway 12L. When the fixed-position lidar horizontal scanning angle is 55 deg, the lidar and WL1 measurements will address similar wake locations.

9.1.2.2 Windline 2

Windline 2 (WL2, **Figure 13**) runs perpendicular to the runways, along an imaginary line that intersects runway 12R at the point near where landing aircraft touch down. WL2 is primarily made up of 6-ft anemometer poles. However, TERPS constraints require shorter poles near the runway edges, where 3-ft anemometer poles are used. Near the transitions from 6-ft to 3-ft poles, several 6-ft poles also have anemometers at the 3-ft height to ensure continuous wake tracking over the entire windline. The anemometer poles are spaced nominally 25 ft apart. WL2 anemometer data will be sampled and

Figure 13 Windline 2

digitized at 10 samples per second. However, averages of five consecutive samples will be stored in the data file, resulting in a 2 Hz rate for the stored data.

WL2 will provide wake data for wakes traveling from runway 12L toward runway 12R as high as 100 ft above the ground.

9.1.3 Vortex Sodars

Vortex Sodars are installed near the inside edges of RWY 12R and RWY 12L, close to, but displaced from, the respective end segments of WL1. The Vortex Sodars will provide information concerning the strength of vortices that travel from RWY 12L to RWY 12R and from RWY 12R to RWY 12L. Vortex sodars will track wakes to a height of 400 ft above ground.

9.2 Wind Measurements

The instrumentation deployed at STL for this test will provide wind information from several types of sensors. Wind measurements at the aircraft altitude will be extracted from pulsed lidar data. Wind near the ground (altitudes of 3 ft, 6 ft, and 12 ft) will be available, at 0.5-sec resolution, as a natural consequence of Windline measurements from those anemometers along WL1 and WL2 that are not interacting with wakes. A wind sodar, located at the center of WL1, will provide wind measurements between altitudes of 70 ft and 500 ft. A 3 axis anemometer array mounted on a 30-ft pole located near the center of WL1 will provide measurements of wind speed and direction at an altitude between the that of windline anemometer poles and the wind sodar. Lastly, measurement data will be available from the airport ASOS at 1-min resolution (also at a height of 30 ft).

9.3 Aircraft Event/ID Measurement

Although time is an important factor in correlating data from diverse sensors, it is also important to define the location and time when an arrival aircraft crosses a specific point on its approach to the landing runway. For analysis purposes, it is also necessary to know the type of each approaching aircraft. Since the various wake sensors and other instrumentation will be collecting data continuously, the event of an aircraft passing over a specific point in space at a specific time will be used to define a run file associated with that specific aircraft.

Several instruments are deployed along the approach path to obtain event/ID information.

9.3.1 Laser Range Finders (Altitude Sensors)

A laser range finder is a Class 1 laser that generates a stream of eye-safe laser pulses. Two laser range finders, one for each runway and each pointing upward, will be deployed along the extended runway centerlines of runways 12L and 12R. The timing of the pulse reflections (at a 200 Hz sampling rate) received from the underside of an arriving aircraft at a range finder determines the distance to (height above ground of) the aircraft.

The runway 12L Laser Range Finder (**Figure 14**) is located approximately 2,683 ft from the threshold; the runway 12R Laser Range Finder is located approximately 1,689 ft from the threshold.

Figure 14 Pressure and Altitude Sensors for RWY 12L

9.3.2 Pressure Sensors

Pressure sensors (**Figure 14**) will be co-located with the two laser range finders. An aircraft generates lift by replacing the volume of air it occupies and directing its momentum downward, resulting in a pressure signature on the ground. When the aircraft is close to the ground, its pressure field can be measured using ground-based instrumentation. The pressure sensors will be used as event markers to supplement the laser range finders. By co-locating the pressure sensors and laser range finders, each pressure measurement will be made at the same time that an altitude measurement is made, thereby enabling estimates of relative aircraft weight and speed to be derived. Since initial wake strength is a function of aircraft weight, estimates of aircraft weight will allow a more complete analysis of wake lifetime with respect to aircraft weight.

9.3.3 Mode S Squitter Receiver

The single Mode S squitter receiver deployed at STL is a passive unit that detects and decodes transmissions from aircraft Mode S transponders on 1090 MHz. The Mode S code within every Modes S message provides the aircraft type. (Technically the Mode S identifier is effectively the aircraft tail number, from which the manufacturer and model are found using a database.) The baro altimeter information within certain Mode S messages provides a measure of aircraft altitude. While often not corrected to the airport barometric setting (and thus not a reliable measure of aircraft height above the airport), the changes in baro altitude during an approach can be combined with aircraft height information from the pertinent laser range finder to generate an altitude profile.

9.3.4 TAMIS

Data on aircraft operations at STL — including aircraft type and landing runway — are available off line from the Total Aircraft Management Information System (TAMIS). This alternative data source will be used to correlate with Mode S receiver information.

9.3.5 ASDE-X Multilateration System

An Airport Surface Detection Equipment, Mode X (ASDE-X) is being deployed at STL as an enhancement to the airport surveillance equipment. The STL ASDE-X includes a multilateration system for tracking aircraft (horizontal position) on approach to runways 12L/12R to an accuracy of 30 ft. The STL multilateration system, scheduled for initial operational capability in May 2004, will be used as an enhancement to (and a crosscheck on) laser range finder and pressure sensor data.

10. DATA ACQUISITION AND STORAGE

10.1 Network Architectures

All sensors/instruments will be linked with and have their data stored within the STL Wake Turbulence Computer Center (WTCC, **Figure 15**) in the American Airlines Training Center building. The STL Wake Turbulence Field Sensor Network (WTFSN, **Figure 16**), which comprises a number of remote wake and wind sensors, is linked by fiber optic cable to the STL WTCC.

10.1.1 Wake Turbulence Computer Center Network

The STL WTCC network is linked directly to the following wake and ancillary sensors: pulsed lidar, runway 12R laser range finder, runway 12R pressure sensor, and Mode S squitter receiver. It is also linked by fiber optic cable to the STL WTW network and to a GPS receiver/time server. The STL WTCC network includes the following workstations:

- Lidar Real Time Display Workstation – This workstation will be used to control the Pulsed Lidar and display intermediate data at the main STL WTCC. This workstation is part of the pulsed lidar package purchased from CTI.
- Lidar Offline Processing Workstations – These two workstations, located at the Volpe Center, will be used to perform off-line processing and visualization of the raw pulsed lidar data. The IDL Software (Research Systems, Inc.) will be installed on these computers.

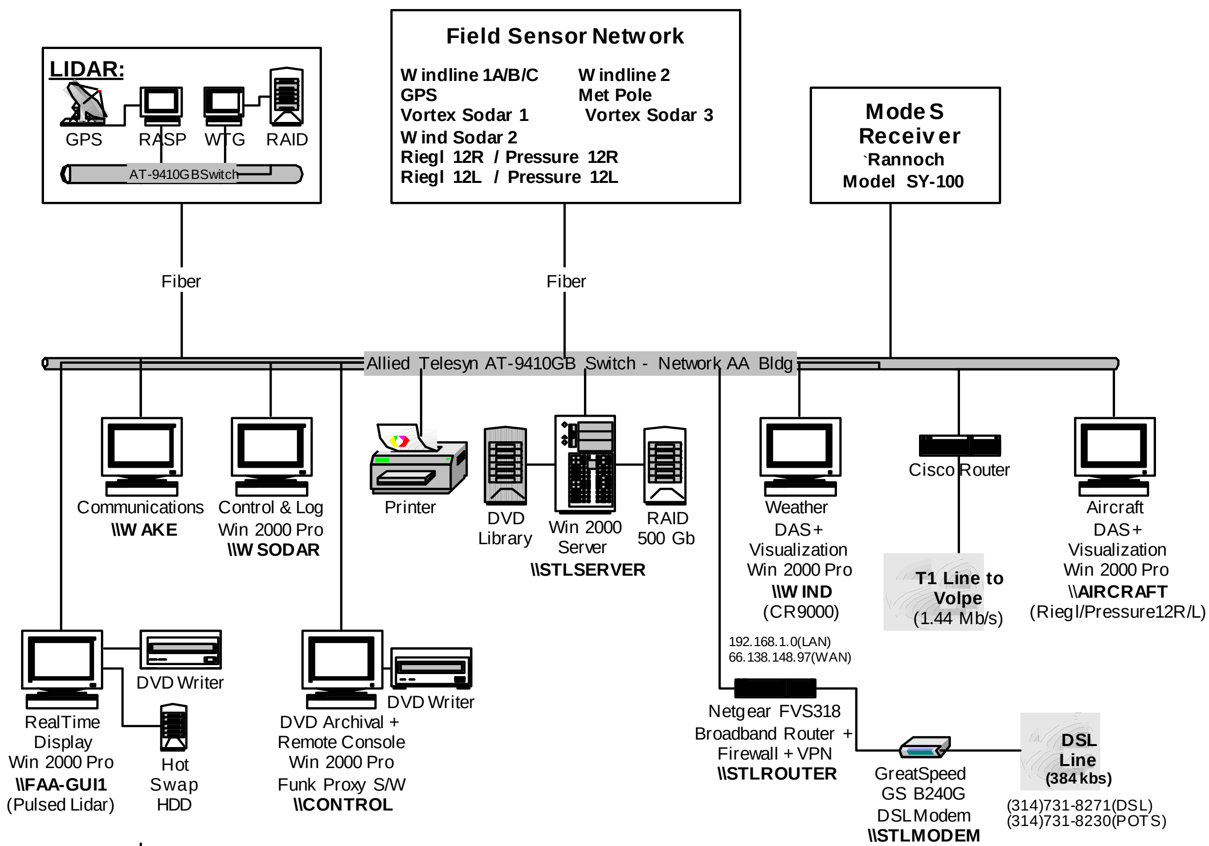

Figure 15 STL Wake Turbulence Computer Center Network

- Sodar Control & Logging Workstation – This workstation will be used to control the Wind and two Vortex Sodars and log the raw sodar data.
- Remote Access Console Workstation – This workstation will be used to provide management access to any of the other computers locally on site, or remotely from off-site using the Funk Software Proxy Server capability. It will also be used

to archive a small amount of the raw data onto DVD media in a manually attended mode. It will also be equipped with a hot swap HDD assembly compatible with the pulsed lidar RAID system.

- Aircraft DAS and Visualization Workstation – This workstation will be used to log and visualize aircraft arrival related data.
- Windline Control and Logging Workstation – This workstation will be used to monitor, log, process, and display Windline data.
- Printer – A printer for routine black and white printing and a color printer for color diagrams and pictures are part of the complement of support instrumentation at the STL WTCC.

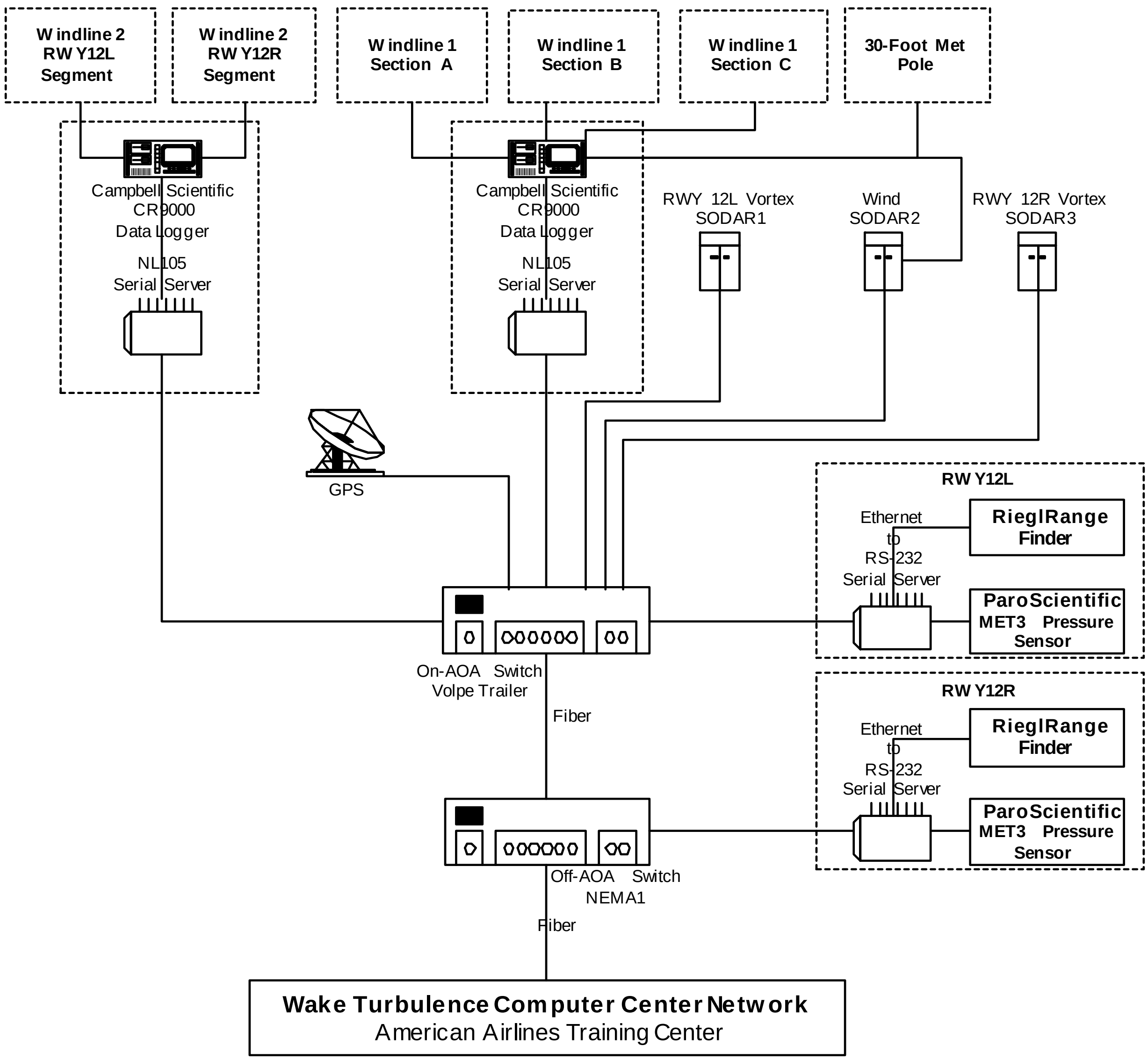

Figure 16 Wake Turbulence Field Sensor Network

10.1.2 Wake Turbulence Field Sensor Network

The STL Wake Turbulence Field Sensor Network links the following sensors to the STL WTCC in the American Airlines Training Center building: Windline 1, Windline 2, meteorological sensors on the 30-ft MET tower, vortex sodars associated with RWY 12R and RWY 12L, range finder and pressure sensor associated with RWY 12L, and the wind sodar.

10.2 Data Handling

The fixed-position pulsed lidar generates an extremely large amount of data — without preprocessing and under unattended operation, approximately 15G bytes per day. Data generated at such a high rate does not lend itself to effective download to the Volpe Center through even a dedicated T1 line. For this test, downloading to DVDs and transporting the data will be employed, since the alternatives are to have attended operation and/or employ a significant degree of data preprocessing.

Windline data, on the other hand, is not so voluminous and, because of the fiber optic link between the STL WTCC and the STL WTSN, lends itself to downloading to the Volpe Center from the STL WTCC in the American Airlines Training Center building. As a backup, there will be on-site transfer of windline data to DVDs or CD-ROMs which will be transported to the Volpe Center. In all cases — i.e., for the Pulsed Lidar, the Windlines, and the other data producing instrumentation — backup copies of the raw data will also be generated to ensure against loss.

11. DATA PROCESSING

The processing of STL data will be conducted in three steps:

1. Inter-relating sensor data to aircraft track events;
2. Converting raw data to wake tracks; and
3. Storing related data into an accessible database.

The result of these steps will be a database for use in support of the STL analysis effort. However, in order to ensure that acquired raw data remains a viable and available source for further additional processing or analytical verification, the raw STL data will be retained in archival form.

The first step in the data processing will be to establish the association between the wake sensor data (Windlines, pulsed lidar, and Vortex sodars) and aircraft arrival events as derived from the Reigl-Laser/Pressure-transducer and the Mode S squitter aircraft identification. TAMIS data, acquired off-line, will be used for aircraft arrival data verification purposes.

The second step comprises converting raw sensor data to wake tracks using the event data derived in step one. Since there are inherent differences in nature of the raw data files obtained with Windlines and Vortex sodars from those obtained from the pulsed lidar, a more complex process of relating pulsed lidar wake tracks to aircraft arrival event data is required. Although some consideration will be given to simplifying this process for the pulsed lidar, this consideration will not result in any delay in developing the pulsed lidar processing results using the current more complex process.

The third step involves storing the resultant wake tracks in a relational database to support the ensuing data analysis.

The approach to be taken, once STL Phase 2 has begun, will be to process sensor and Meteorological (Met) data on a monthly basis thereby producing interim results. All previous interim results will be integrated with the current month's data. This will result in an increasingly larger set of statistical aircraft wake data.

A robust storage system will be employed, and will include backup copies. Since data will be processed for a month at a time, the storage system will accommodate the DVDs containing the intermediate results and their backup copies produced as a result. This represents an effective way of providing fundamental storage of data.

The processing system shown in **Figure 17** is currently in place to support the data processing effort. However, manipulating large data files and databases requires expanding the capability of the system. The processing workstation is being upgraded to house 4 terabyte (TB) of data storage that will be loaded with data received from STL on DVDs. This will facilitate processing the data on a monthly basis and will also allow appending and processing newer data with the previous data as the 12-month STL data acquisition effort continues.

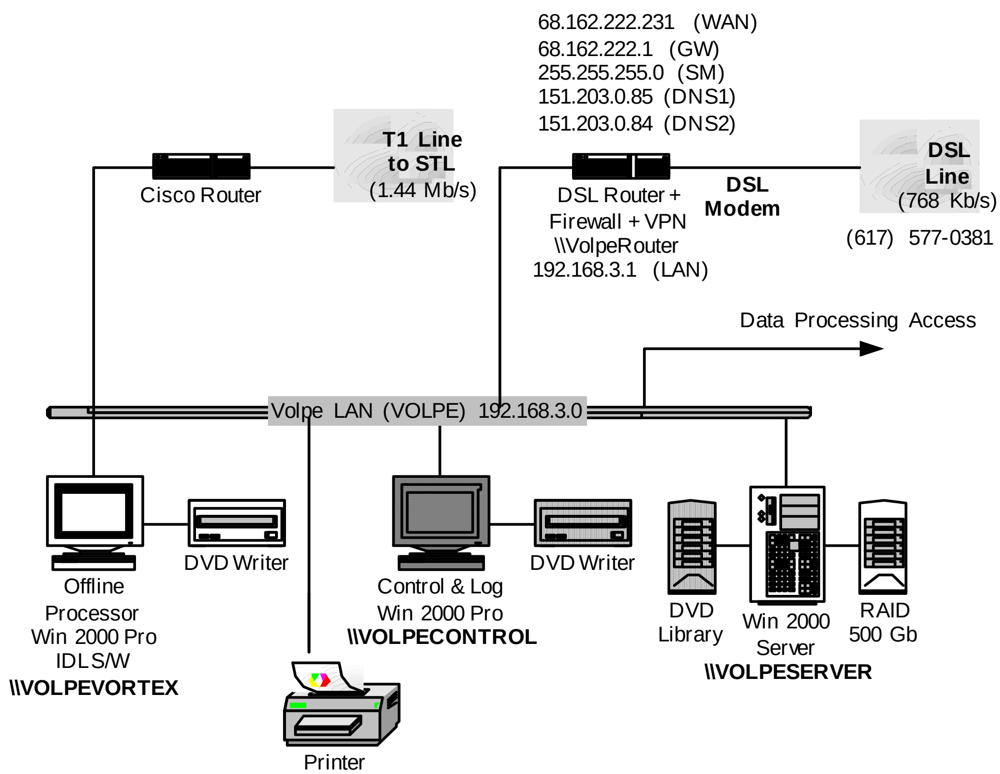

Figure 17 Volpe Center Data Processing System Architecture

All wake and wind sensors record data continuously without regard for aircraft arrival events. The critical sensors for providing aircraft event data are the Reigl Laser Range Finder and the Pressure Sensors; the critical sensor for determining aircraft type is the Mode S squitter receiver. Additional crosschecking for both event and ID data will be the offline TAMIS data. Event information will be correlated using GPS-derived UTC time, and that information will be used to process the continuously recorded wake sensor data to derive run files.

Table 3 presents the steps that will be taken to create a database of run files, containing all the information relating to specific aircraft arrivals. The first four steps define the runway, event time, and aircraft. There are real time sources for those data, as discussed previously, but they are supplemented with offline data obtained from other sources. The remaining steps provide wake and other data that are associated with that specific aircraft arrival. The run files will be stored in an accumulating database on a hard drive that will be used for the statistical analyses.

Relative to **Table 3**, the significant effort required to carry out the steps, particularly the **Action** steps calling for <u>*Process*</u>, is masked by the simplicity of the tabular presentation. <u>*Process*</u> should be read as implementation of a processing algorithm. The **Action** step calling for *Go* is an instruction to access the raw data file. The **Action** step calling for *Create* names the processed data file appropriately for analysis retrieval, and the **Action** step calling for *Store* appends the new processed data file to the appropriate file in the database that contains all the other processed data files pertaining to that specific aircraft arrival.

Table 3 Procedure for Creating Aircraft Arrival Run File

<u>For the Windlines, Vortex Sodars, Wind Sodars, and Meteorological Sensors</u>

1. **Action** - Was there an aircraft? – no, go back to 1; yes, go to 2
2. **Data (runway**) - What runway was it on? (RWY12L, RWY 12R)
3. **Data (event time)** - What time did it pass over the event markers? (determine intersection times, based on event time, when the detected aircraft passed over the intersection of the sensor scan regions (pulsed lidar, Windline 1, Windline 2, Wind Sodar, 30-foot MET pole, and Vortex Sodars) and the arrival runway centerline.
4. **Data (aircraft type)** - What was the aircraft type? (Mode S squitter, TAMIS)
5. **Action** - Go to the Windline 1 data file
6. **Action** - <u>*Process*</u> the Windline 1 data starting at the Windline 1 intersection time.
7. **Action** - *Create* a Windline 1 run file
8. **Action** - *Store* the new Windline 1 run file
9. **Action** - Go to the Windline 2 data file.
10. **Action** - <u>*Process*</u> the Windline 2 data starting at the Windline 2 intersection time.
11. **Action** - *Create* a Windline 2 run file
12. **Action** - *Store* the new Windline 2 run file
13. **Action** - Go to the Wind Sodar data file, the 30-foot pole anemometer data,
14. **Action** - <u>*Process*</u> the Wind Sodar data starting at the Wind Sodar intersection time.
15. **Action** - *Create* a Wind Sodar run file
16. **Action** - *Store* the new Wind Sodar run file
17. **Action** - Go to the 30-foot pole anemometer data file.
18. **Action** - <u>*Process*</u> the 30-foot pole anemometer data starting at the 30-foot pole anemometer intersection time.

19. **Action** - *Create* a 30-foot pole anemometer run file
20. **Action** - *Store* the new 30-foot pole anemometer run file
21. **Action** - Go to the Vortex Sodar 1 data file
22. **Action** - Process the Vortex Sodar 1 data starting at the Vortex Sodar 1 line intersection time.
23. **Action** - *Create* a Vortex Sodar 1 run file
24. **Action** - *Store* the new Vortex Sodar 1 run file
25. **Action** - Go to the Vortex Sodar 2 data file
26. **Action** - Process the Vortex Sodar 2 data starting at the Vortex Sodar 2 line intersection time.
27. **Action** - *Create* a Vortex Sodar 2 run file
28. **Action** - *Store* the new Vortex Sodar 2 run file

For the Pulsed Lidar

1. **Action** - Was there an aircraft? – no, go back to 1; yes, go to 2
2. **Data (runway)** - What runway was it on? (RWY12L, RWY 12R)
3. **Data (event time)** - What time did it pass over the event markers?
4. **Action** - Go to the pulsed lidar data file and determine the scan angle active at the time
5. **Action** - *Process* the pulsed lidar data starting at the pulsed lidar scan plane intersection time
6. **Action** - *Create* a pulsed lidar run file
7. **Action** - *Store* the new pulsed lidar run file

12. DATA QUALITY ASSURANCE

For the windlines, sodars, range finders, pressure sensors, pulsed lidar and ASOS, a report containing the precise locations and elevations of the sensors will be made by a professional surveyor. Wiring and polarity checks will be generated, and logged in the baseline configuration files. In addition, an on-site GPS clock synchronization check between various GPS receivers and GPS time logged in the data file will be carried out periodically.

An infrastructure integrity check of three times a week is planned. The following items are checked:

- Physical connectivity (i.e., assuring that data files are created);
- Network is operation (i.e., generated data files are being pushed to file server);
- Health of the sensors:
  - Pulsed lidar self check (monitoring via CTI automated software): CTI will regularly check the laser vital signs via remote access. These checks may become more frequent as health-check trends indicate performance degradations;
  - Pressure sensor is crosschecked with the ambient pressure published on the Internet as a baseline;
  - The Sodars can be crosschecked with each other via their real time displays;

- Mode S is checked on site once a week;
- 30 ft pole is crosschecked with the first range gate of the wind sodar.

St. Louis University personnel will backup data DVDs and help check sensor status weekly. The system network administrator will check the connectivity and sensor health weekly. Finally, another level of system integrity check will be carried out at the Volpe Center once a week. All the various checks are to be logged.

Since ASOS and TAMIS data are FAA operational data, only data integrity checks are carried out (i.e., only ensuring that received ASCII data are not corrupted).

In the event that propeller anemometers need to be replaced, spares are available on site, and additional units can be ordered with a 2-day turn around time. A spare laser range finder is also at the Volpe Center, and a temporary spare pressure sensor can be used. A replacement of the pressure sensor has a six-week turn around time. The pulsed lidar comes with an array of high priority spares included in the government purchase, and a spare transceiver is available as a loaner from CTI with one week turnaround time.

Regarding the major maintenance, only the windlines require close monitoring since they are mechanical in nature. Lessons learned from past experience showed that the following are common causes for individual windline elements to degrade:

- Frozen propellers;
- Poles knocked over by airport vehicles;
- Grass interference; and
- Corrosion from jet blast.

The St. Louis University support person will perform a physical check for the first three items — particularly the mechanical integrity of the propellers and poles — as part of his/her weekly duties. As a matter of course, the following maintenance will be conducted as precautions:

- One year replacement of propeller anemometers; and
- One year refurbishment of pulsed lidar transceiver.

13. DATA ANALYSIS OBJECTIVES

Data analysis will be performed to provide data for AFS to conduct the safety assessment of the proposed rule change to the 2500 ft minimum centerline separation for dependent parallel arrivals during IMC. There are four objectives for this data analysis.

13.1 Development of Analysis Scenarios for Safety Assessments

The first objective is the identification of relevant operational scenarios to be used by AFS in the assessment of safety. This analysis will be focused on outliers in the data, those cases which may tend to determine the limits of the proposed procedure change.

Cases of maximum lateral wake transport will be analyzed for the specific operational conditions that are associated with them (e.g., generating aircraft types, specific head and crosswind conditions, ceilings and visibilities). AFS can then use this analysis to identify and establish normal and worst case wake scenarios to be coupled with aircraft performance on approaches for ASAT analysis.

13.2 Enhancement and Validation of Wake Behavior Models

The second objective is the enhancement and validation of the wake behavior model within ASAT. This will be accomplished through the merging of wake track data (a history of wake lateral position, strength, height above ground, and time) with the type of aircraft generating the wake and the wind conditions during wake transport. Analysis of the wake behavior as a function of generating aircraft weight class and wind will be performed as well as the limits of wake transport as a function of those same parameters. This analysis will be compared to current models of wake behavior for the same parameters and the model will be updated to reflect the field data.

In support of this objective, the following data will be collected:

- Aircraft types, arrival times, and assigned runways;
- Head wind and crosswind strengths for each arrival; and
- Wake track data to include:
  - Lateral transport;
  - Lifetime;
  - Height above ground;
  - Initial wake strength;
  - Wake strength as a function of time;
  - Ceiling and visibility.

These data will be collected at multiple locations to support the AFS application of analysis tiles along the approach corridor.

13.3 Identification of Operational Constraints to Support Safety Objectives

The third objective of the data analysis is to identify additional operational constraints or potential modification that may be considered by AFS to meet the overall safety objective of the proposed procedural change. This analysis will couple lateral wake transport, as well as wake height above the ground with operational parameters (aircraft types, and wind conditions, ceilings and visibility) to identify possible constraints on those operational parameters which may prove useful in gaining margins of safety for the proposed procedure change. Air Traffic Procedures will also be a customer to this alternatives analysis to ensure that the proposed constraints can reasonably and safely be applied in the Air Traffic Control (ATC) environment. This third objective will also support the identification of additional wake avoidance solutions for Near and Mid-term time frames as denoted in the RMP.

13.4 Refinement of Data Collection Strategies

The fourth objective of the data analysis is the verification and refinement of the current wake data collection methods and sensor location selection criteria. This data collection plan is designed to collect wake and environmental data over the section of the final approach where additional field data is needed to validate and enhance the wake behavior models in ASAT. Specific wake sensor locations, algorithms and data collection methods are designed to focus the data collection efforts on those locations that are most likely to determine the limits of the proposed procedure change. Analysis of the multiple lidar scan angles and sensor locations will permit identification of the positions along the approach corridors where maximum wake transport occurs. An additional pulsed lidar will be used in a mobile mode to collect data outside of the range of the fixed sensors to provide additional verification of the appropriate geographic area for data collection. A third pulsed lidar will provide cross verification at the windline locations. Wake tracking algorithms and scan locations will be modified as necessary based on the ongoing data analysis. As the analysis progresses, some sensors, such as the mobile pulsed lidars STL2 and STL3 and one or more vortex sodars, may be moved to better serve the overall measurement effort.

As shown in **Figure 4**, the vortex wake sensors are located to provide data for three analysis tiles which straddle the parallel runways at STL. Two types of cross reference analysis will be performed for these sensors. In the middle tile, sensor verification will be performed between the WL1 and the vortex sodars as well as between the wind sodar and the met tower. Sensor verification will also be performed between WL1 and WL2. The pulsed lidar will provide overlapping coverage with WL1 and the vortex sodars. These verification activities will be performed at the onset and throughout the 12 month data collection effort.

The following types of analyses are expected to be conducted, based on experience from SFO and in anticipation of the needs of the proposed procedure. Additional analyses will be defined as findings are observed from this set and discussed with AFS:

- Characterize wake behavior by aircraft type, wind condition and ceiling/ visibility condition;
- Characterize wake behavior during use of procedure through analysis of wake data collected during ceiling and wind conditions to periods when the proposed procedure will be used;
- For all aircraft types within a weight category and for each weight category, the following analyses will be performed to characterize the relationships among wake transport, wake decay, wake descent, crosswind level and wake formation height — e.g., relationships between:
    - Crosswind levels and rate of wake decay
    - Wake descent and the rate of wake decay
    - Wake descent and transport distance
    - Wake strength and wake transport distance
    - Wake strength and time

- Wake generation height and wake transport distance
- Initial wake strength and wake descent.

These analyses will be applied to two types of operations at STL: (1) single runway arrivals with 2.5 nmi in-trail separation during IMC with ceilings from 1200 ft to 250 ft, and (2) the proposed dependent parallel arrivals procedure with 1.5 nmi diagonal separation during IMC with ceilings from 1200 ft to 250 ft:

- For arrivals to 12R, characterize the wakes that remain near the approach path for trailing aircraft to 12R at a distance of 2.5 to 3 nmi (75-80 sec) and those wakes that transport near the approach path for trailing aircraft on 12L at a distance of 1.5 to 3 nmi (45–80 sec).
- For arrivals to 12L, characterize the wakes that remain near the approach path for trailing aircraft to 12L at a distance of 2.5 to 3 nmi (75-80 sec) and those wakes that transport near the approach path for trailing aircraft on 12R at a distance of 1.5 to 3 nmi (45–80 sec).

The wake characterization will include the number, percent and strength of wakes that would be encountered by a hypothetical trailing aircraft. The analysis will take account of the different descent profiles for the two runways — i.e., non-vertical guided LDA approach 12L and straight in approach with electronic glideslope guidance to 12R.

These analyses will target the same critical regions of the approach corridor that ASAT covers with tiles. That critical region extends from the thresholds of both runways to a point up the approach path where actual aircraft separation will begin to approach the current separation minimums — roughly to the outer marker. These analyses will investigate the effects of terrain, relative differences in approach path heights between the runways, as well as any local biases in meteorological effects. These analyses will be conducted first for all aircraft within the Large and Small weight categories, and may be extended to other aircraft types as time permits and operational need dictates.

APPENDIX 1: STL INSTRUMENTATION LOCATIONS

In order to facilitate processing and analysis of the STL wake data, a fixed sensor coordinate system, called a location coordinate system (LCS), has been developed. The origin of this coordinate system is at the intersection of the centerline of RWY 12L and its threshold. The LCS is oriented such that the positive Y-axis is in the direction of RWY 12R and the positive X-axis is up the glideslope. This orientation puts all the STL Wake Turbulence Program sensors in the first quadrant an orientation that is consistent with those in use for other airport test programs. A graphic of this coordinate system is shown in **Figure 18**. Specific detail concerning the LCS relative to RWY 12L threshold is shown in **Figure 19**.

Because the STL wake instrumentation installation is extensive, it may be difficult to obtain a good general representation of sensor locations relative to the runway centerlines and thresholds and their separation distances from the LCS fixed coordinate system. To help alleviate this, a secondary coordinate system, called a distance coordinate system (DCS), was developed. The axes of the DCS are parallel to the corresponding axes of the LCS and are a feature of every sensor in the STL instrumentation suite. A graphic of this coordinate system is shown in **Figure 20**. The primary purpose of the DCS is to provide orthogonal distances, direct distances, and directions from each of the sensors to the two runway centerlines and thresholds Although it has not been done here, a cross reference table could be developed that shows the distance and direction of each sensor from every other sensor. This might be useful, for example, for establishing the separation distances between adjacent anemometer poles. Nevertheless, such a table could be generated using the tabular information provided.

It is also important to note that the crosswind and headwind anemometer propellers are offset from their mounting poles. Further, the crosswind anemometers are oriented toward RWY 12R on WL1 and toward RWY 12L on WL2. All headwind anemometers are oriented down the glideslope. The graphics in **Figure 21** and **Figure 22**.

Table 4 through **Table 9** provide information concerning the coordinates, using LCS, of the various sensors and instrumentation deployed as part of the STL Wake Turbulence Test Program. Using DCS, the orthogonal distances of the various sensors from the runway centerlines and thresholds are also provided along with other distances and angles that might prove useful. These Tables were derived using the original information provided to the FAA Central Region Office to undergo Part 77 TERPS analysis to obtain their approval for installation of the instrumentation at STL and verified with measurements and surveys taken after the installation.

Table 10 contains sensor coordinates, orthogonal and direct distances, and angle information relative to the runway centerlines and thresholds, distances between key elements of each sensor configuration, and important airport layout information.

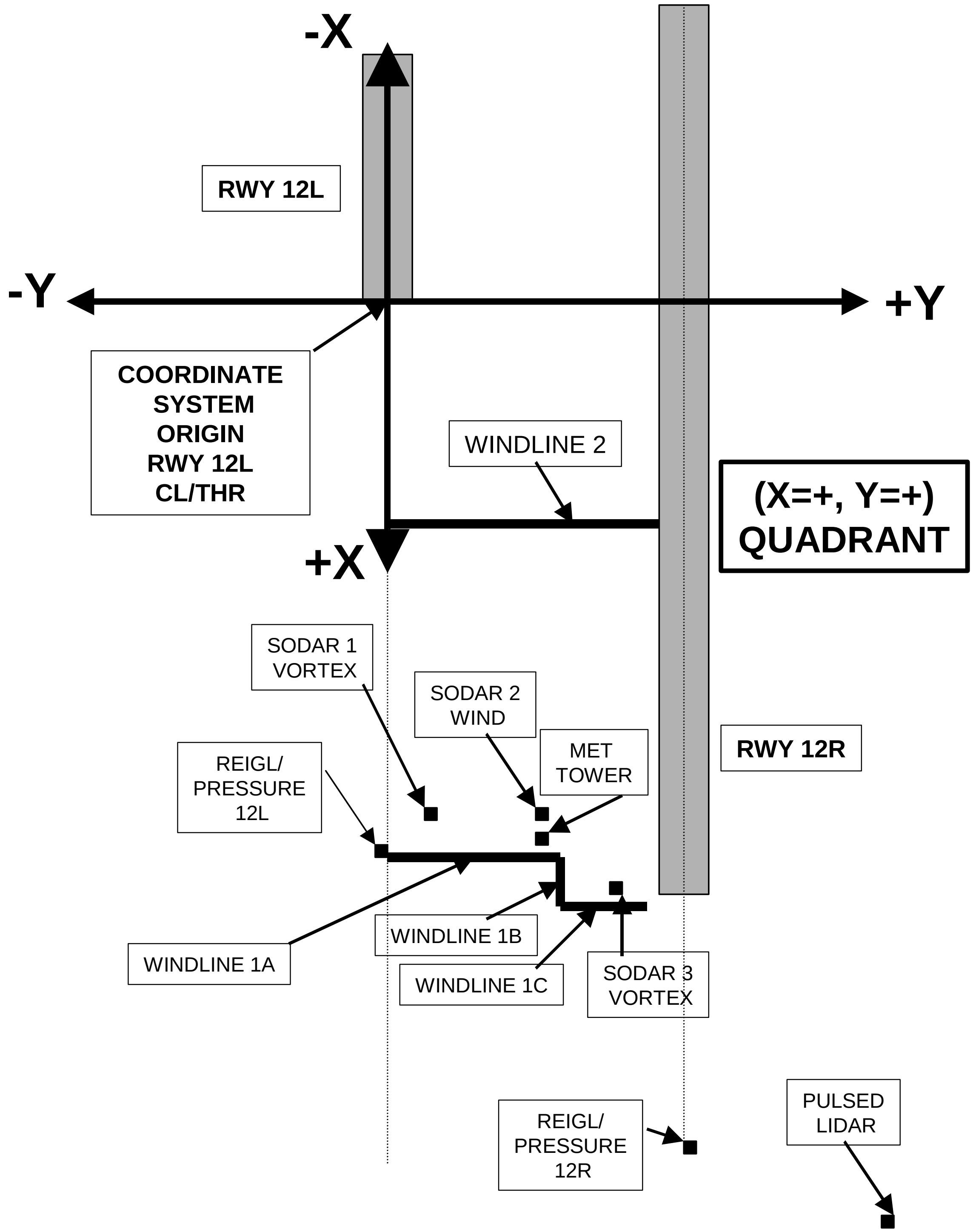

Figure 18 Sensor Location Coordinate System

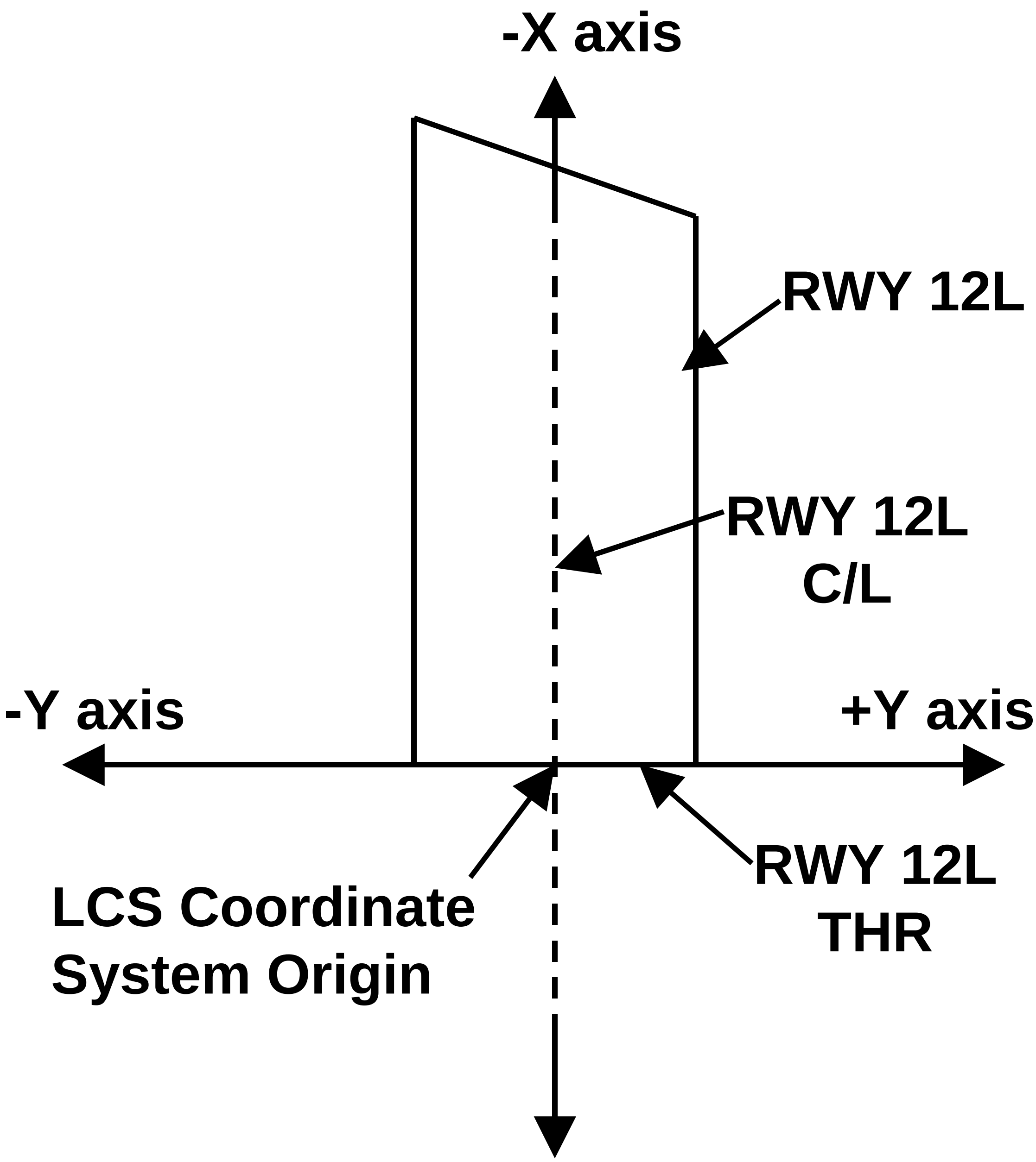

Figure 19 Details of Location Coordinate System

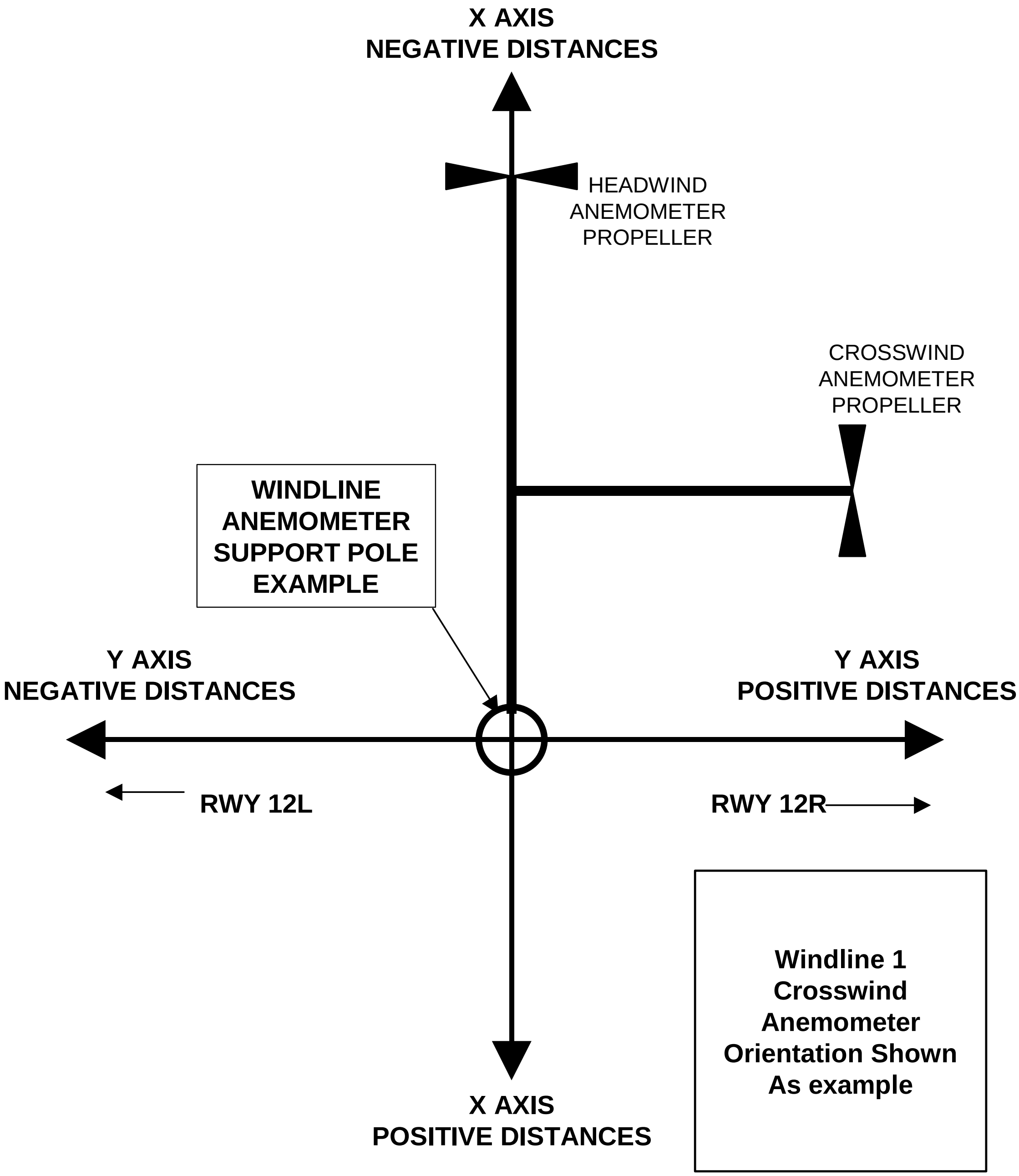

Figure 20 Sensor Distance Coordinate

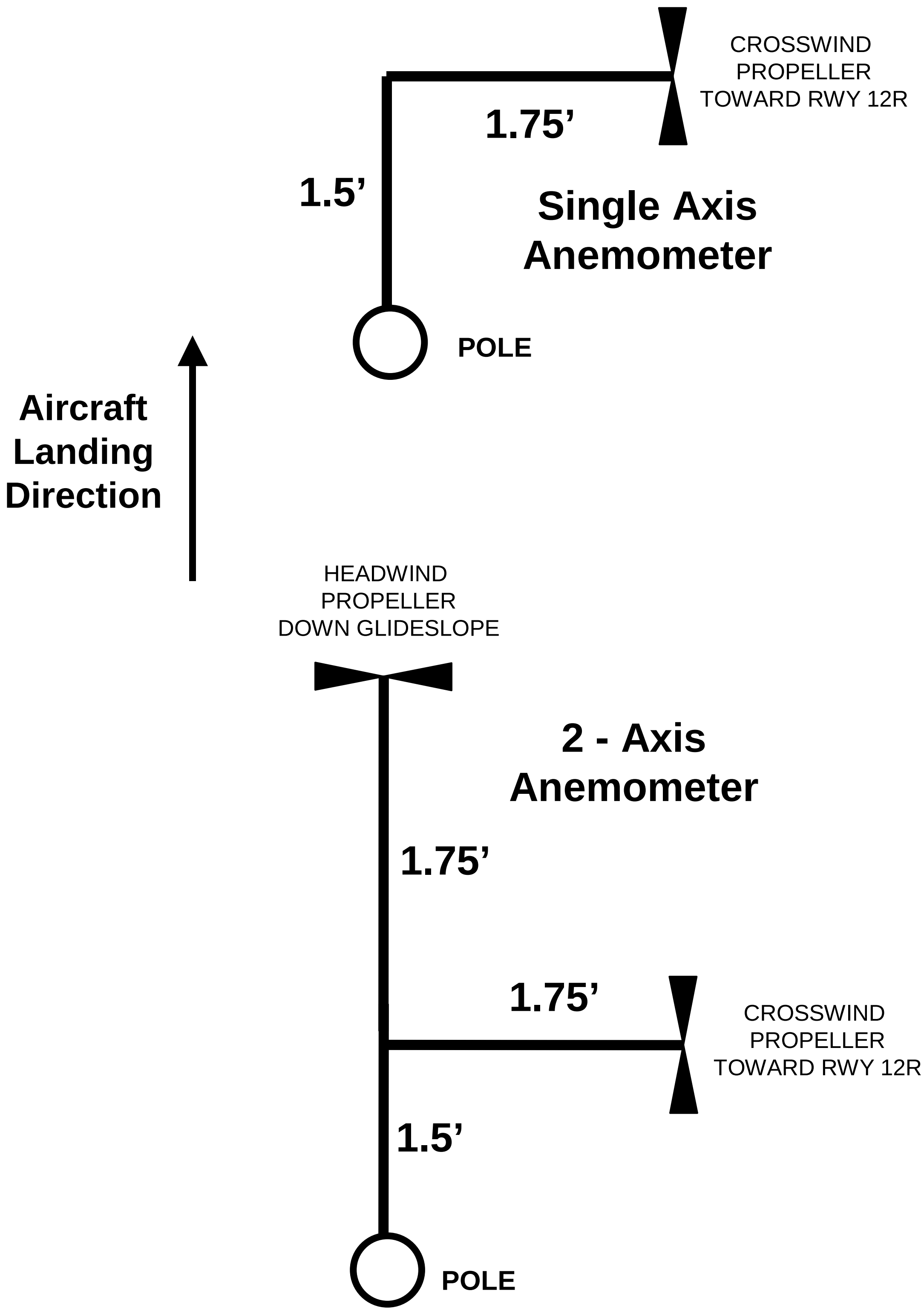

Figure 21 Windline 1 Anemometer Offsets

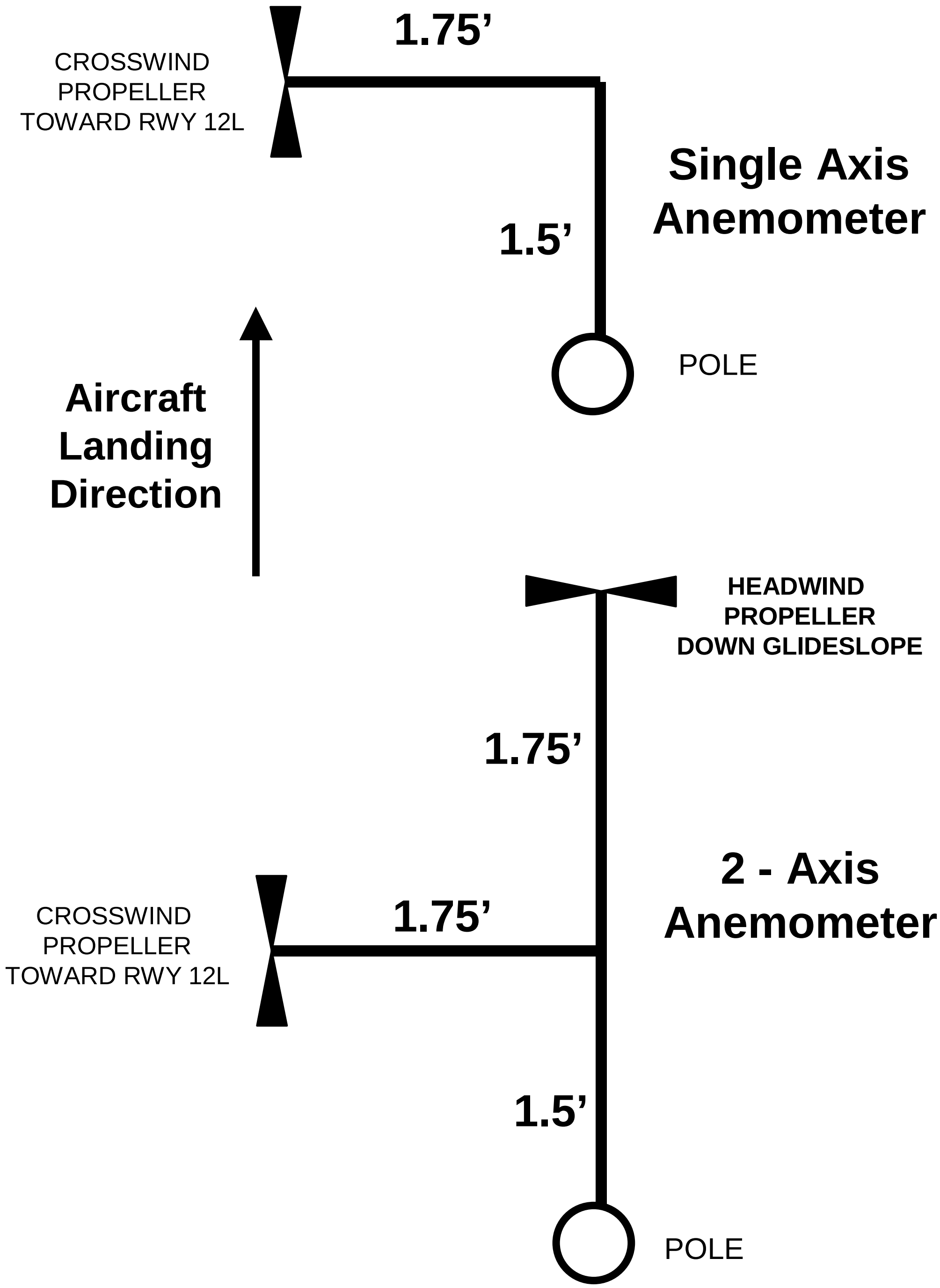

Figure 22 Windline 2 Anemometer Offsets

Table 4 Windline 1 Section A (Rwy 12L End) Element Locations

LOCATION COORDINATE SYSTEM ORIGIN IS THE POINT OF INTERSECTION OF RWY 12L CENTERLINE WITH THE RWY 12L THRESHOLD. POSITIVE Y AXIS IS TOWARD RWY 12R AND POSITIVE X AXIS IS UP THE GLIDESLOPE								DISTANCE COORDINATE SYSTEM ORIGIN IS THE SENSOR OR ELEMENT UNDER CONSIDERATION			
ELEMENT DESIGNATION	SENSOR ELEMENT SYMBOL	X COORD POLE feet	Y COORD POLE feet	X COORD ANEM PROP feet	Y COORD ANEM PROP feet	SENSOR HEIGHT feet	GROUND ELEVATION feet	X DIST: POLE TO RWY 12L THR feet	X DIST; POLE TO RWY 12R THR feet	Y DIST: POLE TO RWY 12L C/L feet	Y DIST: POLE TO RWY 12R C/L feet
WL1A POLE 1 CROSS	WL1AP1X12	2683.15	25.08	2681.65	26.83	12	544.52	-2683.16	352.37	-25.08	1274.92
WL1A POLE 2 CROSS	WL1AP2X12	2683.15	50.17	2681.65	51.92	12	544.51	-2683.16	352.37	-50.17	1249.83
WL1A POLE 3 CROSS	WL1AP3X12	2683.15	75.75	2681.65	77.25	12	544.30	-2683.16	352.37	-75.75	1224.25
WL1A POLE 4 CROSS	WL1AP4X12	2683.15	100.92	2681.65	102.42	12	544.06	-2683.16	352.37	-100.92	1199.08
WL1A POLE 5 CROSS	WL1AP5X12	2683.15	126.33	2681.65	127.83	12	544.10	-2683.16	352.37	-126.33	1173.67
WL1A POLE 6 CROSS	WL1AP6X12	2683.15	151.33	2681.65	152.83	12	543.88	-2683.16	352.37	-151.33	1148.67
WL1A POLE 7 CROSS	WL1AP7X12	2683.15	176.50	2681.65	178.00	12	543.72	-2683.16	352.37	-176.50	1123.50
WL1A POLE 8 CROSS	WL1AP8X12	2683.15	201.75	2681.65	203.25	12	543.54	-2683.16	352.37	-201.75	1098.25
WL1A POLE 9 CROSS	WL1AP9X12	2683.15	226.83	2681.65	228.33	12	543.40	-2683.16	352.37	-226.83	1073.17
WL1A POLE 10 CROSS	WL1AP10X12	2683.15	252.08	2681.65	253.67	12	543.56	-2683.16	352.37	-252.08	1047.92
WL1A POLE 11 CROSS	WL1AP11X12	2683.15	277.25	2681.65	278.83	12	543.32	-2683.16	352.37	-277.25	1022.75
WL1A POLE 12 CROSS	WL1AP12X12	2683.15	310.83	2681.65	312.08	12	542.94	-2683.16	352.37	-310.83	989.17
WL1A POLE 13 CROSS	WL1AP13X12	2683.15	336.00	2681.65	337.25	12	542.46	-2683.16	352.37	-336.00	964.00
WL1A POLE 14 CROSS	WL1AP14X12	2683.15	361.25	2681.65	362.50	12	542.10	-2683.16	352.37	-361.25	938.75
WL1A POLE 15 CROSS	WL1AP15X12	2683.15	386.33	2681.65	387.58	12	541.95	-2683.16	352.37	-386.33	913.67
WL1A POLE 16 CROSS	WL1AP16X12	2683.15	411.50	2681.65	412.75	12	541.71	-2683.16	352.37	-411.50	888.50
WL1A POLE 17 CROSS	WL1AP17X12	2683.15	436.58	2681.65	437.83	12	541.48	-2683.16	352.37	-436.58	863.42
WL1A POLE 17 CROSS	WL1AP17X3	2683.15	436.58	2681.65	437.83	3	541.48	-2683.16	352.37	-436.58	863.42
WL1A POLE 18 CROSS	WL1AP18X12	2683.15	461.92	2681.65	463.17	12	541.24	-2683.16	352.37	-461.92	838.08
WL1A POLE 18 CROSS	WL1AP18X3	2683.15	461.92	2681.65	463.17	3	541.24	-2683.16	352.37	-461.92	838.08
WL1A POLE 19 CROSS	WL1AP19X12	2683.15	487.17	2681.65	488.42	12	540.94	-2683.16	352.37	-487.17	812.83
WL1A POLE 19 CROSS	WL1AP19X3	2683.15	487.17	2681.65	488.42	3	540.94	-2683.16	352.37	-487.17	812.83
WL1A POLE 20 CROSS	WL1AP20X12	2683.15	512.25	2681.65	513.50	12	540.80	-2683.16	352.37	-512.25	787.75
WL1A POLE 20 CROSS	WL1AP20X3	2683.15	512.25	2681.65	513.50	3	540.80	-2683.16	352.37	-512.25	787.75
WL1A POLE 21 CROSS	WL1AP21X12	2683.15	537.42	2681.65	538.67	12	540.34	-2683.16	352.37	-537.42	762.58
WL1A POLE 21 CROSS	WL1AP21X3	2683.15	537.42	2681.65	538.67	3	540.34	-2683.16	352.37	-537.42	762.58
WL1A POLE 22 CROSS	WL1AP22X12	2683.15	562.42	2681.65	563.67	12	540.05	-2683.16	352.37	-562.42	737.58
WL1A POLE 22 CROSS	WL1AP22X3	2683.15	562.42	2681.65	563.67	3	540.05	-2683.16	352.37	-562.42	737.58
WL1A POLE 23 CROSS	WL1AP23X12	2683.15	587.84	2681.65	589.08	12	539.73	-2683.16	352.37	-587.84	712.16
WL1A POLE 23 HEAD	WL1AP23H12	2683.15	587.84	2679.90	587.33	12	539.73	-2683.16	352.37	-587.84	712.16
WL1A POLE 23 VERT	WL1AP23V12	2683.15	587.84	2683.15	587.33	12	539.73	-2683.16	352.37	-587.84	712.16
WL1A POLE 23 CROSS	WL1AP23X6	2683.15	587.84	2681.65	589.08	6	539.73	-2683.16	352.37	-587.84	712.16
WL1A POLE 23 HEAD	WL1AP23H6	2683.15	587.84	2679.90	587.33	6	539.73	-2683.16	352.37	-587.84	712.16
WL1A POLE 23 CROSS	WL1AP23X3	2683.15	587.84	2681.65	589.08	3	539.73	-2683.16	352.37	-587.84	712.16
WL1A POLE 23 HEAD	WL1AP23H3	2683.15	587.84	2679.90	587.33	3	539.73	-2683.16	352.37	-587.84	712.16

Table 5 Windline 1 Section B (Center Section) Element Locations

LOCATION COORDINATE SYSTEM ORIGIN IS THE POINT OF INTERSECTION OF RWY 12L CENTERLINE WITH THE RWY 12L THRESHOLD. POSITIVE Y AXIS IS TOWARD RWY 12R AND POSITIVE X AXIS IS UP THE GLIDESLOPE								DISTANCE COORDINATE SYSTEM ORIGIN IS THE SENSOR OR ELEMENT UNDER CONSIDERATION			
ELEMENT DESIGNATION	SENSOR ELEMENT SYMBOL	X COORD POLE feet	Y COORD POLE feet	X COORD ANEM PROP feet	Y COORD ANEM PROP feet	SENSOR HEIGHT feet	GROUND ELEVATION feet	X DIST: POLE TO RWY 12L THR feet	X DIST; POLE TO RWY 12R THR feet	Y DIST: POLE TO RWY 12L C/L feet	Y DIST: POLE TO RWY 12R C/L feet
WL1B POLE 24 CROSS	WL1BP24X12	2696.57	618.84	2695.07	620.08	12	539.63	-2696.58	338.95	-618.84	681.16
WL1B POLE 25 CROSS	WL1BP25X12	2797.90	618.84	2796.41	620.08	12	540.87	-2797.91	237.62	-618.84	681.16
WL1B POLE 26 CROSS	WL1BP26X12	2898.24	618.84	2896.74	620.08	12	542.80	-2898.24	137.29	-618.84	681.16
WL1B POLE 27 CROSS	WL1BP27X12	2998.99	618.84	2997.49	620.08	12	544.86	-2998.99	36.54	-618.84	681.16

Table 6 Windline 1 Section C (Rwy 12R End) Element Locations

LOCATION COORDINATE SYSTEM ORIGIN IS THE POINT OF INTERSECTION OF RWY 12L CENTERLINE WITH THE RWY 12L THRESHOLD. POSITIVE Y AXIS IS TOWARD RWY 12R AND POSITIVE X AXIS IS UP THE GLIDESLOPE								DISTANCE COORDINATE SYSTEM ORIGIN IS THE SENSOR OR ELEMENT UNDER CONSIDERATION			
ELEMENT DESIGNATION	SENSOR ELEMENT SYMBOL	X COORD POLE feet	Y COORD POLE feet	X COORD ANEM PROP feet	Y COORD ANEM PROP feet	SENSOR HEIGHT feet	GROUND ELEVATION feet	X DIST: POLE TO RWY 12L THR feet	X DIST; POLE TO RWY 12R THR feet	Y DIST: POLE TO RWY 12L C/L feet	Y DIST: POLE TO RWY 12R C/L feet
WL1C POLE 28 CROSS	WL1CP28X12	3052.49	618.84	3050.99	620.08	12	547.06	-3052.49	-16.96	-618.84	681.16
WL1C POLE 29 CROSS	WL1CP29X12	3052.49	644.09	3050.99	645.33	12	546.63	-3052.49	-16.96	-644.09	655.91
WL1C POLE 29 CROSS	WL1CP29X3	3052.49	644.09	3050.99	645.33	3	546.63	-3052.49	-16.96	-644.09	655.91
WL1C POLE 30 CROSS	WL1CP30X12	3052.49	669.09	3050.99	670.33	12	546.29	-3052.49	-16.96	-669.09	630.91
WL1C POLE 30 CROSS	WL1CP30X3	3052.49	669.09	3050.99	670.33	3	546.29	-3052.49	-16.96	-669.09	630.91
WL1C POLE 31 CROSS	WL1CP31X12	3052.49	694.09	3050.99	695.33	12	546.09	-3052.49	-16.96	-694.09	605.91
WL1C POLE 31 CROSS	WL1CP31X3	3052.49	694.09	3050.99	695.33	3	546.09	-3052.49	-16.96	-694.09	605.91
WL1C POLE 32 CROSS	WL1CP32X12	3052.49	719.25	3050.99	720.50	12	545.53	-3052.49	-16.96	-719.25	580.75
WL1C POLE 32 CROSS	WL1CP32X3	3052.49	719.25	3050.99	720.50	3	545.53	-3052.49	-16.96	-719.25	580.75
WL1C POLE 33 CROSS	WL1CP33X12	3052.49	744.25	3050.99	745.50	12	545.15	-3052.49	-16.96	-744.25	555.75
WL1C POLE 33 CROSS	WL1CP33X3	3052.49	744.25	3050.99	745.50	3	545.15	-3052.49	-16.96	-744.25	555.75
WL1C POLE 34 CROSS	WL1CP34X12	3052.49	769.42	3050.99	770.67	12	544.57	-3052.49	-16.96	-769.42	530.58
WL1C POLE 34 CROSS	WL1CP34X3	3052.49	769.42	3050.99	770.67	3	544.57	-3052.49	-16.96	-769.42	530.58
WL1C POLE 35 CROSS	WL1CP35X12	3052.49	794.75	3050.99	796.00	12	543.98	-3052.49	-16.96	-794.75	505.25
WL1C POLE 35 CROSS	WL1CP35X3	3052.49	794.75	3050.99	796.00	3	543.98	-3052.49	-16.96	-794.75	505.25
WL1C POLE 36 CROSS	WL1CP36X12	3052.49	819.92	3050.99	821.17	12	543.33	-3052.49	-16.96	-819.92	480.08
WL1C POLE 36 CROSS	WL1CP36X3	3052.49	819.92	3050.99	821.17	3	543.33	-3052.49	-16.96	-819.92	480.08
WL1C POLE 37 CROSS	WL1CP37X12	3052.49	844.59	3050.99	845.83	12	542.66	-3052.49	-16.96	-844.59	455.41
WL1C POLE 37 CROSS	WL1CP37X3	3052.49	844.59	3050.99	845.83	3	542.66	-3052.49	-16.96	-844.59	455.41
WL1C POLE 38 CROSS	WL1CP38X12	3052.49	869.42	3050.99	870.67	12	542.21	-3052.49	-16.96	-869.42	430.58
WL1C POLE 38 CROSS	WL1CP38X3	3052.49	869.42	3050.99	870.67	3	542.21	-3052.49	-16.96	-869.42	430.58
WL1C POLE 39 CROSS	WL1CP39X3	3052.49	919.25	3050.99	920.50	3	541.80	-3052.49	-16.96	-919.25	380.75
WL1C POLE 40 CROSS	WL1CP40X3	3052.49	944.25	3050.99	945.50	3	541.63	-3052.49	-16.96	-944.25	355.75
WL1C POLE 41 CROSS	WL1CP41X3	3052.49	969.17	3050.99	970.42	3	541.21	-3052.49	-16.96	-969.17	330.83
WL1C POLE 42 CROSS	WL1CP42X3	3052.49	994.17	3050.99	995.42	3	540.79	-3052.49	-16.96	-994.17	305.83
WL1C POLE 43 CROSS	WL1CP43X3	3052.49	1019.25	3050.99	1020.50	3	540.36	-3052.49	-16.96	-1019.25	280.75
WL1C POLE 44 CROSS	WL1CP44X3	3052.49	1044.42	3050.99	1045.67	3	540.08	-3052.49	-16.96	-1044.42	255.58
WL1C POLE 45 CROSS	WL1CP45X3	3052.49	1069.42	3050.99	1070.67	3	539.41	-3052.49	-16.96	-1069.42	230.58
WL1C POLE 46 CROSS	WL1CP46X3	3052.49	1094.09	3050.99	1095.33	3	538.39	-3052.49	-16.96	-1094.09	205.91
WL1C POLE 47 CROSS	WL1CP47X3	3052.49	1119.42	3050.99	1120.67	3	537.38	-3052.49	-16.96	-1119.42	180.58
WL1C POLE 48 CROSS	WL1CP48X3	3052.49	1144.09	3050.99	1145.33	3	536.88	-3052.49	-16.96	-1144.09	155.91

Table 7 Windline 2 Element Locations (Part 1/2)

LOCATION COORDINATE SYSTEM ORIGIN IS THE POINT OF INTERSECTION OF RWY 12L CENTERLINE WITH THE RWY 12L THRESHOLD. POSITIVE Y AXIS IS TOWARD RWY 12R AND POSITIVE X AXIS IS UP THE GLIDESLOPE								DISTANCE COORDINATE SYSTEM ORIGIN IS THE SENSOR OR ELEMENT UNDER CONSIDERATION			
ELEMENT DESIGNATION	SENSOR ELEMENT SYMBOL	X COORD POLE feet	Y COORD POLE feet	X COORD ANEM PROP feet	Y COORD ANEM PROP feet	SENSOR HEIGHT feet	GROUND ELEVATION feet	X DIST: POLE TO RWY 12L THR feet	X DIST; POLE TO RWY 12R THR feet	Y DIST: POLE TO RWY 12L C/L feet	Y DIST: POLE TO RWY 12R C/L feet
WL2 POLE 1 CROSS	WL2P1X3	1448.85	102.85	1447.35	101.10	3	533.07	-1448.86	1586.67	-102.85	1197.15
WL2 POLE 2 CROSS	WL2P2X3	1448.85	128.03	1447.35	126.28	3	532.93	-1448.86	1586.67	-128.03	1171.97
WL2 POLE 3 CROSS	WL2P3X3	1448.85	153.36	1447.35	151.61	3	532.66	-1448.86	1586.67	-153.36	1146.64
WL2 POLE 4 CROSS	WL2P4X3	1448.85	178.74	1447.35	176.99	3	531.51	-1448.86	1586.67	-178.74	1121.26
WL2 POLE 5 CROSS	WL2P5X3	1448.85	204.02	1447.35	202.27	3	532.04	-1448.86	1586.67	-204.02	1095.98
WL2 POLE 5 HEAD	WL2P5H3	1448.85	204.02	1445.60	204.02	3	532.04	-1448.86	1586.67	-204.02	1095.98
WL2 POLE 5 CROSS	WL2P5X6	1448.85	204.02	1447.35	202.27	6	532.04	-1448.86	1586.67	-204.02	1095.98
WL2 POLE 5 HEAD	WL2P5H6	1448.85	204.02	1445.60	204.02	6	532.04	-1448.86	1586.67	-204.02	1095.98
WL2 POLE 6 CROSS	WL2P6X3	1448.85	229.35	1447.35	227.60	3	531.42	-1448.86	1586.67	-229.35	1070.65
WL2 POLE 6 CROSS	WL2P6X6	1448.85	229.35	1447.35	227.60	6	531.42	-1448.86	1586.67	-229.35	1070.65
WL2 POLE 7 CROSS	WL2P7X3	1448.85	254.53	1447.35	252.78	3	530.99	-1448.86	1586.67	-254.53	1045.47
WL2 POLE 7 CROSS	WL2P7X6	1448.85	254.53	1447.35	252.78	6	530.99	-1448.86	1586.67	-254.53	1045.47
WL2 POLE 8 CROSS	WL2P8X3	1448.85	280.41	1447.35	278.66	3	530.45	-1448.86	1586.67	-280.41	1019.59
WL2 POLE 8 CROSS	WL2P8X6	1448.85	280.41	1447.35	278.66	6	530.45	-1448.86	1586.67	-280.41	1019.59
WL2 POLE 9 CROSS	WL2P9X3	1448.85	305.74	1447.35	303.99	3	530.24	-1448.86	1586.67	-305.74	994.26
WL2 POLE 9 CROSS	WL2P9X6	1448.85	305.74	1447.35	303.99	6	530.24	-1448.86	1586.67	-305.74	994.26
WL2 POLE 10 CROSS	WL2P10X3	1448.85	331.07	1447.35	329.32	3	529.90	-1448.86	1586.67	-331.07	968.93
WL2 POLE 10 CROSS	WL2P10X6	1448.85	331.07	1447.35	329.32	6	529.90	-1448.86	1586.67	-331.07	968.93
WL2 POLE 11 CROSS	WL2P11X3	1448.85	356.45	1447.35	354.70	3	529.59	-1448.86	1586.67	-356.45	943.55
WL2 POLE 11 CROSS	WL2P11X6	1448.85	356.45	1447.35	354.70	6	529.59	-1448.86	1586.67	-356.45	943.55
WL2 POLE 12 CROSS	WL2P12X3	1448.85	381.83	1447.35	380.08	3	529.24	-1448.86	1586.67	-381.83	918.17
WL2 POLE 12 CROSS	WL2P12X6	1448.85	381.83	1447.35	380.08	6	529.24	-1448.86	1586.67	-381.83	918.17
WL2 POLE 13 CROSS	WL2P13X6	1448.85	407.11	1447.35	405.36	6	529.09	-1448.86	1586.67	-407.11	892.89
WL2 POLE 14 CROSS	WL2P14X6	1448.85	432.59	1447.35	430.84	6	529.01	-1448.86	1586.67	-432.59	867.41
WL2 POLE 15 CROSS	WL2P15X6	1448.85	457.92	1447.35	456.17	6	529.11	-1448.86	1586.67	-457.92	842.08
WL2 POLE 16 CROSS	WL2P16X6	1448.85	483.35	1447.35	481.60	6	528.77	-1448.86	1586.67	-483.35	816.65
WL2 POLE 17 CROSS	WL2P17X6	1448.85	508.78	1447.35	507.03	6	528.26	-1448.86	1586.67	-508.78	791.22
WL2 POLE 18 CROSS	WL2P18X6	1448.85	534.21	1447.35	532.46	6	528.14	-1448.86	1586.67	-534.21	765.79
WL2 POLE 19 CROSS	WL2P19X3	1448.85	559.69	1447.35	557.94	3	527.98	-1448.86	1586.67	-559.69	740.31
WL2 POLE 19 HEAD	WL2P19H3	1448.85	559.69	1445.60	559.69	3	527.98	-1448.86	1586.67	-559.69	740.31
WL2 POLE 19 CROSS	WL2P19X6	1448.85	559.69	1447.35	557.94	6	527.98	-1448.86	1586.67	-559.69	740.31
WL2 POLE 19 HEAD	WL2P19H6	1448.85	559.69	1445.60	559.69	6	527.98	-1448.86	1586.67	-559.69	740.31
WL2 POLE 20 CROSS	WL2P20X6	1448.85	585.07	1447.35	583.32	6	527.82	-1448.86	1586.67	-585.07	714.93

Table 8 Windline 2 Element Locations (Part 2/2)

LOCATION COORDINATE SYSTEM ORIGIN IS THE POINT OF INTERSECTION OF RWY 12L CENTERLINE WITH THE RWY 12L THRESHOLD. POSITIVE Y AXIS IS TOWARD RWY 12R AND POSITIVE X AXIS IS UP THE GLIDESLOPE								DISTANCE COORDINATE SYSTEM ORIGIN IS THE SENSOR OR ELEMENT UNDER CONSIDERATION			
ELEMENT DESIGNATION	SENSOR ELEMENT SYMBOL	X COORD POLE feet	Y COORD POLE feet	X COORD ANEM PROP feet	Y COORD ANEM PROP feet	SENSOR HEIGHT feet	GROUND ELEVATION feet	X DIST: POLE TO RWY 12L THR feet	X DIST; POLE TO RWY 12R THR feet	Y DIST: POLE TO RWY 12L C/L feet	Y DIST: POLE TO RWY 12R C/L feet
WL2 POLE 21 CROSS	WL2P21X6	1448.85	610.40	1447.35	608.65	6	527.65	-1448.86	1586.67	-610.40	689.60
WL2 POLE 22 CROSS	WL2P22X6	1448.85	635.83	1447.35	634.08	6	527.80	-1448.86	1586.67	-635.83	664.17
WL2 POLE 23 CROSS	WL2P23X6	1448.85	661.21	1447.35	659.46	6	527.76	-1448.86	1586.67	-661.21	638.79
WL2 POLE 24 CROSS	WL2P24X6	1448.85	686.69	1447.35	684.94	6	527.61	-1448.86	1586.67	-686.69	613.31
WL2 POLE 25 CROSS	WL2P25X3	1448.85	712.12	1447.35	710.37	3	527.65	-1448.86	1586.67	-712.12	587.88
WL2 POLE 25 CROSS	WL2P25X6	1448.85	712.12	1447.35	710.37	6	527.65	-1448.86	1586.67	-712.12	587.88
WL2 POLE 26 CROSS	WL2P26X3	1448.85	737.45	1447.35	735.70	3	527.91	-1448.86	1586.67	-737.45	562.55
WL2 POLE 26 CROSS	WL2P26X6	1448.85	737.45	1447.35	735.70	6	527.91	-1448.86	1586.67	-737.45	562.55
WL2 POLE 27 CROSS	WL2P27X3	1448.85	762.93	1447.35	761.18	3	528.17	-1448.86	1586.67	-762.93	537.07
WL2 POLE 27 CROSS	WL2P27X6	1448.85	762.93	1447.35	761.18	6	528.17	-1448.86	1586.67	-762.93	537.07
WL2 POLE 28 CROSS	WL2P28X3	1448.85	789.76	1447.35	788.01	3	528.52	-1448.86	1586.67	-789.76	510.24
WL2 POLE 28 CROSS	WL2P28X6	1448.85	789.76	1447.35	788.01	6	528.52	-1448.86	1586.67	-789.76	510.24
WL2 POLE 29 CROSS	WL2P29X3	1448.85	814.74	1447.35	812.99	3	528.92	-1448.86	1586.67	-814.74	485.26
WL2 POLE 29 CROSS	WL2P29X6	1448.85	814.74	1447.35	812.99	6	528.92	-1448.86	1586.67	-814.74	485.26
WL2 POLE 30 CROSS	WL2P30X3	1448.85	840.12	1447.35	838.37	3	529.70	-1448.86	1586.67	-840.12	459.88
WL2 POLE 30 CROSS	WL2P30X6	1448.85	840.12	1447.35	838.37	6	529.70	-1448.86	1586.67	-840.12	459.88
WL2 POLE 31 CROSS	WL2P31X3	1448.85	865.55	1447.35	863.80	3	530.06	-1448.86	1586.67	-865.55	434.45
WL2 POLE 31 CROSS	WL2P31X6	1448.85	865.55	1447.35	863.80	6	530.06	-1448.86	1586.67	-865.55	434.45
WL2 POLE 32 CROSS	WL2P32X3	1448.85	890.93	1447.35	889.18	3	530.30	-1448.86	1586.67	-890.93	409.07
WL2 POLE 32 HEAD	WL2P32H3	1448.85	890.93	1445.60	890.93	3	530.30	-1448.86	1586.67	-890.93	409.07
WL2 POLE 32 CROSS	WL2P32X6	1448.85	890.93	1447.35	889.18	6	530.30	-1448.86	1586.67	-890.93	409.07
WL2 POLE 32 HEAD	WL2P32H6	1448.85	890.93	1445.60	890.93	6	530.30	-1448.86	1586.67	-890.93	409.07
WL2 POLE 33 CROSS	WL2P33X3	1448.85	916.31	1447.35	914.56	3	530.31	-1448.86	1586.67	-916.31	383.69
WL2 POLE 34 CROSS	WL2P34X3	1448.85	941.74	1447.35	939.99	3	530.25	-1448.86	1586.67	-941.74	358.26
WL2 POLE 35 CROSS	WL2P35X3	1448.85	967.12	1447.35	965.37	3	530.40	-1448.86	1586.67	-967.12	332.88
WL2 POLE 36 CROSS	WL2P36X3	1448.85	992.60	1447.35	990.85	3	530.35	-1448.86	1586.67	-992.60	307.40
WL2 POLE 37 CROSS	WL2P37X3	1448.85	1020.18	1447.35	1018.43	3	530.85	-1448.86	1586.67	-1020.18	279.82
WL2 POLE 38 CROSS	WL2P38X3	1448.85	1043.61	1447.35	1041.86	3	531.00	-1448.86	1586.67	-1043.61	256.39
WL2 POLE 39 CROSS	WL2P39X3	1448.85	1068.29	1447.35	1066.54	3	530.75	-1448.86	1586.67	-1068.29	231.71
WL2 POLE 40 CROSS	WL2P40X3	1448.85	1093.42	1447.35	1091.67	3	529.40	-1448.86	1586.67	-1093.42	206.58
WL2 POLE 41 CROSS	WL2P41X3	1448.85	1118.65	1447.35	1116.90	3	529.35	-1448.86	1586.67	-1118.65	181.35
WL2 POLE 42 CROSS	WL2P42X3	1448.85	1143.73	1447.35	1141.98	3	529.85	-1448.86	1586.67	-1143.73	156.27

Table 9 Ancillary Instrumentation Locations

LOCATION COORDINATE SYSTEM ORIGIN IS THE POINT OF INTERSECTION OF RWY 12L CENTERLINE WITH THE RWY 12L THRESHOLD. POSITIVE Y AXIS IS TOWARD RWY 12R AND POSITIVE X AXIS IS UP THE GLIDESLOPE						DISTANCE COORDINATE SYSTEM ORIGIN IS THE SENSOR OR ELEMENT UNDER CONSIDERATION			
ELEMENT DESIGNATION	SENSOR ELEMENT SYMBOL	X COORD SENSOR feet	Y COORD SENSOR feet	SENSOR HEIGHT feet	GROUND ELEVATION feet	X DIST: SENSOR TO RWY 12L THR feet	X DIST: SENSOR TO RWY 12R THR feet	Y DIST: SENSOR TO RWY 12L C/L feet	Y DIST: SENSOR TO RWY 12R C/L feet
RWY12L REIGL	12LR	2683.15	0.00	6	543.97	-2683.16	352.37	0.00	1300.00
RWY12L PRESSURE	12LP	2683.15	0.00	6	543.97	-2683.16	352.37	0.00	1300.00
RWY12R REIGL	12RR	4726.70	1300.00	6	552.71	-4724.70	-1689.17	-1300.00	0.00
RWY12R PRESSURE	12RP	4726.70	1300.00	6	552.71	-4724.70	-1689.17	-1300.00	0.00
SODAR 1 VORTEX[1]	S1V	2578.15	239.46	8		-2578.16	457.37	-239.50	1060.50
SODAR 1 VORTEX[2]	S1V								
SODAR 2 WIND	S2W	2580.15	575.13	8		-2580.16	455.37	-575.22	724.78
SODAR 3 VORTEX	S3V	2950.49	981.67	8		-2963.91	71.62	-981.76	318.24
MET POLE CROSS	MX30	2641.32	587.84	30	539.53	-2641.33	394.20	-587.93	712.07
MET POLE HEAD	MH30	2641.32	587.84	30	539.53	-2641.33	394.20	-587.93	712.07
MET POLW VERT	MV30	2641.32	587.84	30	539.53	-2641.33	394.20	-587.93	712.07
PULSED LIDAR 1[3]	PL1	5382.13	2407.63	12	575.02	-5395.35	-2360.02	-2407.63	-1107.73
PULSED LIDAR 2[4]	PL2								
PULSED LIDAR 3[5]	PL3								
ASOS	ASOS	1845.50	886.87	30	531.97	-1858.92	1176.61	-886.87	413.13

NOTE 1 - VORTEX SODAR LOCATION UP TO NOVEMBER 9, 2004
NOTE 2 - SODAR 1 VORTEX RELOCATED TO INSIDE END OF WINDLINE 1C NOVEMBER 10, 2004
NOTE 3 - FIXED POSITION PULSED LIDAR
NOTE 4 - SECOND PULSE LIDAR TO BE USED FOR MOBILE OPERATION
NOTE 5 - THIRD PULSE LIDAR TO BE USED IN WINDLINE CROSS VERIFICATION TESTS

Table 10 STL Instrumentation Location Information

ELEMENT	DISTANCE feet	ANGLE degrees	ELEVATION feet	NORTHING	EASTING	LATITUDE	LONGITUDE
WL1AP1			543.97	1064022.5527	856046.2920	38°45'20.36"	-90°22'27.57"
WL1AP23			539.73	1063556.2244	855747.8795	38°45'20.36"	-90°22'27.57"
WL1A INTERSECT OF 12LC/L				1064047.2451	856055.9681	38°45'20.61"	-90°22'27.45"
WL1A INTERSECT OF 12LC/L TO 12L THR	2683.15						
WL1A INTERSECT OF 12RC/L				1062946.0086	855365.0929	38°45'09.73"	-90°22'36.19"
WL1A INTERSECT OF 12RC/L TO 12R THR	352.37						
WL1A PERPENDICULAR TO WL2	1234.30						
WL1AP23 PERPENDICULAR TO 12LC/L	587.84						
WL1AP23 PERPENDICULAR TO 12RC/L	712.16						
WL2P1			532.94	1063299.4122	857048.4625	38°45'13.20"	-90°22'14.93"
WL2P19			527.98	1062917.2999	856804.1397	38°45'09.43"	-90°22'18.02"
WL2 INTERSECT OF 12LC/L				1063391.2287	857101.5040	38°45'14.11"	-90°22'14.26"
WL2/12LC/L INTERSECT TO 12L THR	1448.86						
WL2 INTERSECT OF 12RC/L				1062290.0708	856410.5878	38°45'03.23"	-90°22'23.00"
WL2/12RC/L INTERSECT TO 12R THR	1586.67						
WL2P19 PERPENDICULAR TO 12LC/L	559.69						
WL2P19 PERPENDICULAR TO 12RC/L	740.31						
12L REIGL/PRESS.			544.12	1064043.6470	856059.6929	38°45'20.57"	-90°22'27.40"
12R REIGL/PRESS.			552.71	1064030.7102	853635.7178	38°45'20.47"	-90°22'58.00"
12L REIGL/PRESS. TO 12L THR	2683.16						
12R REIGL/PRESS. TO 12R THR	1689.17						
PL BASE			575.02	1063449.3180	852478.9435	38°45'14.74"	-90°23'12.61"
PL INTERSECT OF 12LC/L				1065488.7380	853758.5678	38°45'34.89"	-90°22'56.43"
PL INTERSECT OF 12RC/L				1064387.6420	853067.6904	38°45'24.01"	-90°23'05.17"
PL TO WL1AP23 DIRECT	3270.68						
ANGLE FROM PL TO WL1AP23 DIRECT		56					
PL TO WL2P19 DIRECT	4357.79						
ANGLE FROM PL TO WL2P19 DIRECT		65					
PL PERPENDICULAR TO 12LC/L	2407.63						
PL PERPENDICULAR TO 12RC/L	1107.73						
PL/R12LC/L INTERSECT TO 12L THR	5395.35						
PL/R12RC/L INTERSECT TO 12R THR	2360.02						
ASOS/TWR			531.97	1062854.4314	856288.3832	38°45'08.81"	-90°22'24.53"
ASOS/TWR INTERSECT OF 12LC/L				1063603.6831	856763.9465		
ASOS/TWR INTERSECT OF 12RC/L				1062507.0691	856067.9062		
ASOS/TWR PERPENDICULAR TO WL1A	835.45						
ASOS/TWR PERPENDICULAR TO WL2	398.85						
ASOS/TWR TO 12LC/L	886.87						
ASOS/TWR TO 12RC/L	413.13						
12L THR			528.16	1062621.8950	858329.2300		
12R THR			539.35	1063134.3700	855067.4000		
12L THR INTERSECT OF 12R				1061521.7906	857639.3648		
NOM. 12R TO 12L THR STAGGER	3035.53						
NOM. 12RC/L TO 12LC/L SEPARATION	1300.00						
ANGLE 12 TO TRUE NORTH		122.0793					

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3. *Air Traffic Control,* Federal Aviation Administration, Order 7110.65N, August 7, 2003.